

**CORDILLERA REAL
GEOLOGICAL RESEARCH PROJECT**

**FOURTH ANNUAL REPORT
(APRIL 1989 – MARCH 1990)**



British Geological Survey

**Keyworth
Nottinghamshire**

PATRI MATRIQUE



Building a makeshift bridge to cross the Río Cascabel.

Incident in Río Cascabel

Not a huge river but dangerous still,
A tumbling canyon down Cayambe's slopes,
Straddled by means of our makeshift bridges,
Saved from the torrent by our flimsy ropes.

Let's pitch our camp there on the other side!
There's a natural bridge for us to use.
The boys have now crossed this mighty tree trunk,
And have started their tasks: there's no time to lose.

Reaching the trunk, I go so carefully.
I see another one lying on top.
To support my weight I touch it merely,
Then my life blanks to a temporary stop.

It's moving away, balanced so finely,
Then coming back like a pendulum stroke.
It takes my legs as if in slow motion,
Into the watery, thundery soak.

Fall in I go! Let the turbulence flow!
Fast over and over, from rock to rock.
My rucksack then starts to slow the foam down.
It's time to wake up from that first great shock!

They say a drowning man will clutch a straw.
A tree root's better if there's one about.
I just lock my arms and just hold on tight,
Then the boys hear my cries and drag me out.

What do you say when your life has been saved?
How long before reality is met?
Then you curse because everything is soaked,
Your glasses are lost, and your notebook's wet!

*Martin Litherland
Inca Treasure
Poems from the Andes of Ecuador*



Condué granite: cut by felsite sheets with chilled margins, in the Río Cofanes above the Río Condué confluence



Camp at Laguna Cubillín

Overseas Development Administration,
Foreign and Commonwealth Office,
United Kingdom of Great Britain
and Northern Ireland

Ministerio de Energía y Minas,
República del Ecuador

CORDILLERA REAL
GEOLOGICAL RESEARCH PROJECT

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(APRIL 1989 – MARCH 1990)

compiled by

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Stalyn Paucar

2026 Edition

Reference

Aspden, J. (compiler) (1990) *Fourth annual report (1989-1990) of the Cordillera Real Geological Research Project, Ecuador*. (Stalyn Paucar, Ed., 2026). Open-File Report of the British Geological Survey, Keyworth (in English) and of INEMIN, Quito (in Spanish).

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ABSTRACT

This report accounts for the work undertaken from April 1989 to March 1990 by the Cordillera Real Geological Research Project: a bilateral (ODA-INEMIN) Technical Cooperation Programme.

As detailed in Chapter 1, it includes as Appendices, and also as a separate Annex of Maps, all the data collected by the Project over the past 12-months.

Geological fieldwork in the early part of the 1989 field season was undertaken in the southern part of the Cordillera Real and two geotraverses between Oñacapa-Yacuambí and Jimbilla-Río Quimi were completed. Additional field studies were also carried out around the area of Tutupali. Subsequently fieldwork concentrated on the filling the remaining gaps in the geotraverse programme which existed between the equator and the Colombia border in the north and between the Rios Paute and Pastaza in the central part of the Cordillera (ca. 1°20'S - 2°35'S). Two 1:250000 geological maps of these latter areas are included in the Annex of Maps, as are copies of all individual 1:50000 geotraverse maps.

In Chapter 2 a revised lithotectonic nomenclature for the Cordillera is presented and the various divisions and subdivisions recognised are described briefly. In addition, the results obtained from both Phase I and Phase II of the Geochronology Programme are discussed and the following thermal/magmatic events are recognised:

- (a) Late Triassic/Early Jurassic (ca. 200 Ma) regional metamorphism with S-type granite intrusion.
- (b) 190-150 Ma major calc-alkaline plutonism and volcanism in the Subandean zone and probably along the eastern flanks of the Cordillera.
- (c) Major dextral shearing event (ca. 130-120). Resetting of older metamorphic ages and greenschist metamorphism of Jurassic volcanics within the Cordillera.
- (d) Major thermal overprinting and resetting event from Late Cretaceous to Early Tertiary.

We speculate that events (c) and (d) relate to accretionary episodes during which magmatic activity was of restricted geographical extent.

The analytical/economic results obtained from both stream sediments and mineralised rock samples are noted in Chapter 3.

1. INTRODUCTION

1.1 Nature of this report

This is the fourth open file Annual Report of the Cordillera Real Geological Research Project: a bilateral Technical Cooperation Project between the Government of Ecuador (Instituto Ecuatoriano de Minería-INEMIN; Ministry of Energy and Mines) and the Government of the United Kingdom of Great Britain and Northern Ireland (Overseas Development Administration-ODA), which began in March 1986. The ODA Technical Cooperation officers are recruited from the British Geological Survey (BGS). The present report covers the period April 1989-March 1990.

The project aims to study the metamorphic rocks of the Cordillera Real of Ecuador. Its objectives are the elucidation of their nature and structure, in order to discover the patterns of metallogenesis and to provide a scientific database to help promote the Ecuadorian Mining Industry.

As with previous Annual Reports this one attempts to include as Appendices all the data which have been obtained by the project over the last 12 months. The main text of the report is produced both in English and Spanish but the Appendices appear in their language of presentation.

1.2 Personnel

The fourth year the Project continued with the following ODA residential staff seconded from BGS:

Dr. Martin Litherland (Project Leader)
Dr. John Aspden

The following INEMIN personnel were assigned to the Project:

Ing. Francisco Viteri Santamaría (Counterpart Project Leader until Oct. 1989)
Ing. Ramiro Bermúdez Almeida (Counterpart Project Leader from Nov. 1989)
Ing. Miguel Pozo Torres (Project Counterpart until August 1989)
Lcda. Fabiola Alcocer Carrasco (Mission Secretary)
Sr. Manuel Céleri Ortiz (Field assistant until Nov. 1989)
Sr. Laureano Saltos Unda (Field assistant from Nov. 1989)

1.3 Summary of Project activities: April 1989 – March 1990

1.3.1 Reconnaissance field programme

Copies of the individual field reports are given in Appendix 1 however the corresponding geological traverse maps are presented as a separate annex to the main report.

The following geotraverses and field studies were undertaken in the Cordillera during the period April 1989-March 1990:

- (a) Field studies in the area of the Ríos Yanayacu, Patate, Pastaza and Quijos (Appendix 1a; Report only) (Litherland).
- (b) Geotraverse from Monte Olivo to Río Condué and field studies in the area of Río Minas (Appendix 1b; Geological map, No. 1) (Litherland).
- (c) Geotraverse from Las Hollas to Río San Jorge via La Bonita and La Sofía (Appendix 1c; Geological map, No. 2) (Litherland).
- (d) Geotraverse from La Bonita to Puerto Libre (Appendix 1c; Geological map No. 2) (Litherland).
- (e) Geotraverse from Oñacapa to Yacuambí (Appendix 1d; Geological map, No. 3) (Aspden and Viteri).
- (f) Geotraverse from Jimbilla to Río Quimi (Appendix 1a; Geological map, No. 3) (Aspden and Viteri).
- (g) Geotraverse from Tutupali to Ortega Alto and Río Campana Urco. Field studies in the Río Chuchumbleza (Appendix 1e; Geological map, No. 4) (Viteri).
- (h) Geotraverse from Atillo to Macas (Río Abanico). (Appendix 1f; Geological map, No. 5) (Aspden).
- (i) Geotraverse from Alao to Palora via Huamboya (Appendix 1f; Geological map, No. 6) (Aspden).
- (j) Geotraverse along the Río Tutanangoza to Río Ojal, field studies in the areas El Azul, Sigsig to Peggy Mine, Río Illushín and the Puyo to Baños Road (Appendix 1g; Geological map of Río Tutanangoza to Río Ojal, No. 7) (Aspden and Bermúdez).

1.3.2 Geochronology programme (Phase II)

Collection of material for Phase II of the geochronology programme, both from the Cordillera Real and El Oro province, was completed by March 1989. Details of this sampling programme are to be found in Dr. Harrison's "visit Report" (Appendix 2a).

The results from Phase II are given in Dr. Harrison's report entitled 'Radiometric ages (Rb-Sr, K-Ar and Sm-Nd) for rocks from the Cordillera Real, Ecuador' (Appendix 2b).

In addition to these results several outstanding K-Ar determinations were also completed by Dr. Rundle. (See Appendix 2c).

1.3.3 Whole-rock chemical analyses

During the past year a limited number of major and trace element whole-rock analyses have been obtained from the following plutons and metaplutons in the Cordillera Real and El Oro:

Plutons and metaplutons	Analyses
Zamora batholith	9
Abitagua batholith	10
Tres Lagunas suite	18
Azafrán batholith	6
Sabanilla metapluton	14
Marcabelí pluton (El Oro)	4
Valladolid metapluton	4
Tampanchi mafic complex	2

The analyses which were carried out at the University of Keele, U.K. are given in Appendix 3. The location of the samples prefixed by -SH- are given in Harrison's report (Appendix 2a) and those prefixed by -CR- are given in Dr Rundle's report (Appendix 3, in Litherland, 1988).

1.3.4 Petrographic studies

Dr. Fortey (BGS, Mineral Science Group) visited the project during the early part of 1990 (Jan 20 - March 03). The purpose of Dr. Fortey's visit was two-fold. Firstly, to give an introductory course on igneous and metamorphic petrology to INEMIN geologists using as a basis hand specimens and thin sections of rocks collected from the Cordillera Real. This course was very popular and was attended by 13 'students', the limiting factor proved to be the availability of microscopes! A copy of Dr. Fortey's course notes, which contain various thin section descriptions of Cordilleran rocks is included as Appendix 4a.

During his visit Dr. Fortey also carried out more detailed petrographic studies on the following suites of rocks of potential economic interest which had been collected by the project since its initiation in 1986 (see Appendix 4b):

- (1) Central and Eastern belt serpentinites and related rocks (potential for Cr, Ni, Au, Pt).
- (2) The Peltetec ophiolite belt (potential for Cr, Ni, Au, Pt).
- (3) The Oyacachi - Papallacta "Aluminous granite" belt (potential for Sn, W).
- (4) The Tampanchi mafic/ultramafic complex (potential for PGE).
- (5) Nambija gold skarns (presently mined for Au).
- (6) Llanganates and related skarnfields (potential for Cu, Zn, Mo).
- (7) The Monte Olivo pegmatite belt (potential for Sn, W, Nb).

1.3.5 Palaeontological studies

The palynological reports on the Alao and Loja divisions by Dr. J. A. Riding (BGS Biostratigraphy Research Group) and a report by Dr. C. Patterson (Natural History Museum, London) on a Tertiary fossil fish are included as Appendix 5.

1.3.6 Geochemical studies-stream sediment and rock analyses

Routine trace element analyses of stream sediment samples and rocks have been carried out in the INEMIN laboratories in Quito (Appendix 6a). In addition, BP Minerals (now Río Tinto Zinc) and Greenwich Resources have sponsored the analyses of various rock samples at ACME laboratories, Vancouver, Canada, at a CALEB-BRETT laboratories, St. Helens UK (Appendix 6b).

1.3.7 Geochemical studies-heavy mineral concentrates

During the project heavy mineral concentrates have been collected from the Cordillera Real on a routine basis. Following his studies in UK on the identification of heavy minerals Ing. Ramiro Bermúdez has now completed an examination of all the project samples and his findings are presented in Appendix 7.

1.4 Acknowledgements

We are again indebted, for financial and administrative support, to INEMIN through the Gerente General Ing. Leonardo Elizalde C., and to ODA through the Ecuadorian desk officers, Mr. Russell, and Mr. Harris, and Mr. Douglas de Wilton, Aid Officer, British Embassy, Quito.

We also appreciate the scientific support provided by the Gerente Técnico of INEMIN Ing. Wilson Santamaría, and Dr. John Bennett, BGS Regional Geologist, Latin America and Asia.

It is also a pleasure once again to note the contribution to this report made by RTZ (ex-BP Minerals International), Greenwich Resources and Cambrico Exploration. Also, we would like to thank Phil Townsend of BP who has contributed various information relating to the sub-Andean zone to the west of Sucúa and to the west and south west of Puyo.

Numerous other people, in both the public and private sectors in Ecuador have helped the project team and this report with useful exchanges of information. We hope that we can continue working together for the benefit of Ecuadorian geology and the Ecuadorian Mining Industry.

2. GEOLOGY

2.1 Introduction

During the past 12 months work has concentrated on filling those gaps in the regional geotraverse programme which existed between the equator, northwards to the Colombian border, and in that part of the Cordillera between Pastaza and Paute rivers (ca. 1°20'S to 2°35'S). This work has now been completed and, based on the information obtained from the individual geotraverses (Appendix 1 and previous Annual Reports), two 1:250000 scale geological maps have been prepared and are included as Map 8 and Map 9 in the separate annex to the main report (see Fig. 1).

In addition to the above, in the early part of the 1989 field season two geotraverses between Oñacapa (to the east of Saraguro) and Yacuambí, and Jimbilla (to the north of Loja) and the Río Quimi were undertaken (Appendix 1d). In order to complete the regional coverage in the southern part of the Cordillera Ing. Viteri also worked in the Tutupali-Ortega Alto area, in the Río Campana Urco and in the Río Chuchumbleza (Appendix 1e).

Time does not permit a detailed discussion of the individual geotraverses nor of all the data which are included as Appendices in this report. The intention however is to synthesise the more important findings, especially those resulting from Phase I and II of the Geochronology Programme, and to present what we feel represent advances toward obtaining a better understanding of the regional geology of the Cordillera Real.

2.2 Lithotectonic nomenclature of the pre-Cretaceous rocks of the Cordillera Real

In previous Annual Reports the metamorphic and metaplutonic rocks of the Cordillera Real were divided into three principal belts: the Western belt, which was limited to the east by the Baños front, the Central belt, and the Eastern or Sub-Andean belt. While this tripartite division proved to be useful in the past, we believe that it is no longer justified and furthermore, as a result of information collected during the past 12 months, it has become necessary to update some of our previous nomenclature.

The revised lithotectonic nomenclature together with brief descriptions of the various subdivisions, are given in Table 1 and these are discussed further in Section 2.3. It is emphasised however that this scheme is still informal and it is to be expected that further changes will have to be made in the future as more detailed mapping is carried out and, in particular, as more reliable radiometric ages are obtained from the metamorphic rocks of the Cordillera Real.

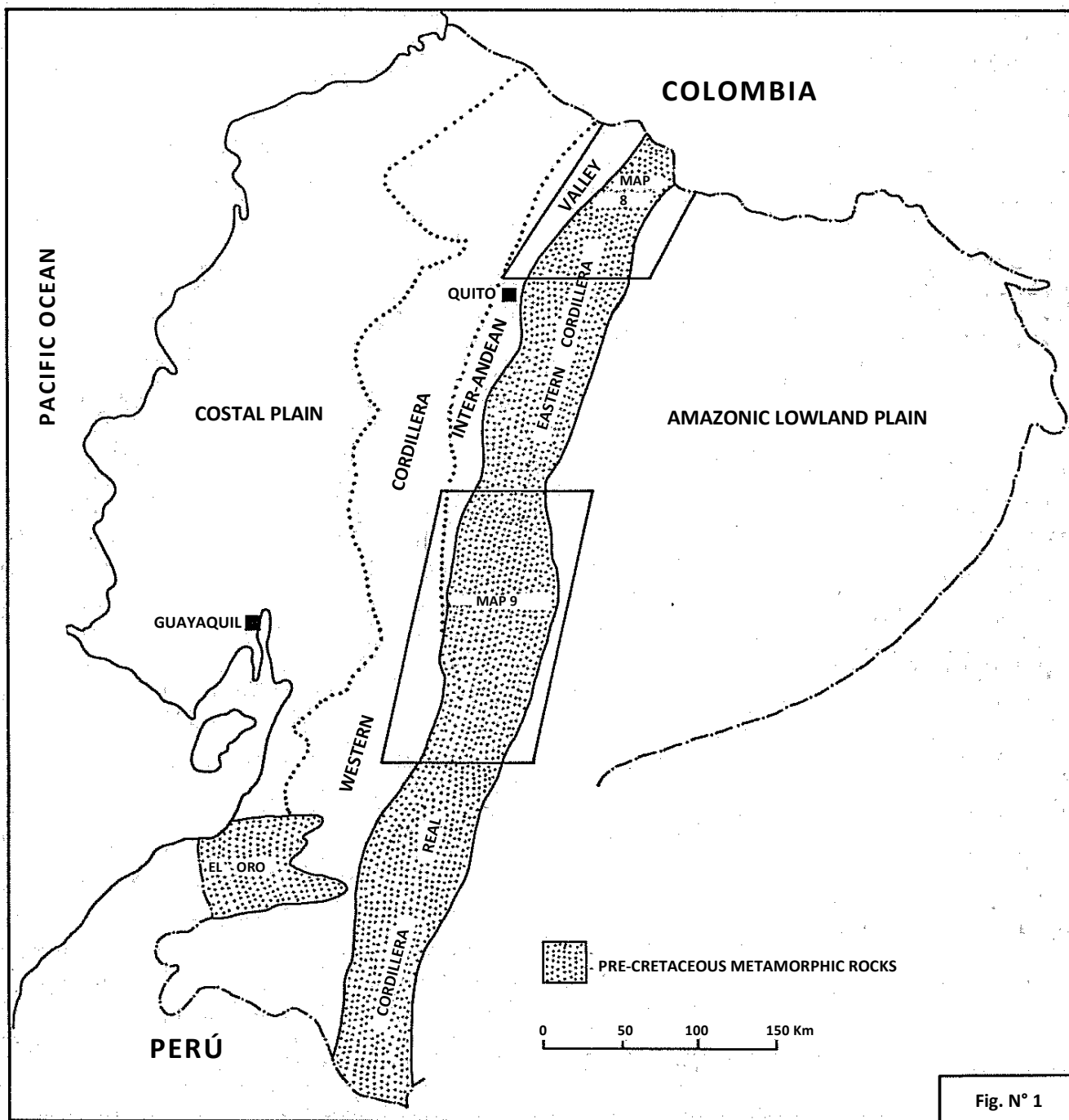


Fig. N° 1

Figure 1. Location of the geological maps 8 and 9 in the Cordillera Real
(1:250000 scale)

Table 1. Informal lithotectonic divisions and subdivisions of the pre-Cretaceous rocks of the Cordillera Real

DIVISION (interpretation)	SUBDIVISION	PRINCIPAL LITHOLOGIES
GUAMOTE (continental sediments/clastic wedge)	Ambuquí	Quartzites and black slates
	Cebadas	Black phyllites and black quartzites
	Guasuntos	Black phyllites and black quartzites
	Punín	Red, black and pale quartzites and phyllites
PELTETEC FAULT		
ALAO (ocean floor, fore-arc, volcanic arc and back-arc)	Peltetec	Dismembered ophiolitic assemblage
	Pacheco	Basaltic greenstones
	Maguazo	Turbidites, cherts, carbonates, andesites, ?olistromes.
	Alao-Paute	Andesitic greenstones, greenschists, agglomerates, minor phyllites.
	El Pan	Volcano/metasedimentary units: green- schists and phyllites.
BAÑOS FRONT		
LOJA (continentally- derived unit: phyllite to paragneiss with 'S- type' granites)	Tres Lagunas	Biotite granite and orthogneiss (S-type character)
	Agoyán	Pelitic schists and paragneiss, common garnet
	Chigüinda	Semipelite (quartzite, black phyllites, schists), minor greenstones
	Sabanilla	Medium-to high-grade orthogneiss and paragneiss
	Monte Olivo	Basaltic amphibolites
SALADO (plutonic unit with volcano-sedimentary sequence)	Santa Bárbara	Biotite ± hornblende ?paragneiss
	Azafrán	Sheared calc-alkaline batholiths
	Upano	Greenstones, metatuffs, metagreywackes and metasediments; minor marbles
	Cerro Hermoso	Marbles and metasediments
APPROXIMATE CRATONIC LIMIT		
ZAMORA (continental plutonic/volcanic arc and olde metamorphics)	Abitagua	Calc-alkaline batholiths (undeformed)
	Misahuallí	Andesites, dacites, basalts, agglomerates (undeformed)
	Isimanchi	Marbles, immature low-grade metasediments and metavolcano-sedimentary units (pre-Abitagua)

2.3 Geology of the pre-Cretaceous rocks of the Cordillera Real

2.3.1 Guamote division

No further work has been carried out on the Guamote division in the south and the available information is summarised in Litherland et al. (1990) and in previous Annual Reports. In regional terms these rocks are interpreted to represent a clastic wedge of predominantly continentally derived material which was deposited on top of the oceanic and fore-arc sequences of the Alao division.

2.3.1.1 Ambuquí subdivision: In the north, (Map 8), rocks which previously were included in the western part of the Ambuquí schist inlier (Baldock, 1982) are now considered to belong to the Guamote division (Table 1). This sequence, which is structurally complex, consists of fine grained, pale reddish and grey quartzites with black to grey slates and phyllites. The eastern contact with the Alao division (Pacheco subdivision) is tectonic (Map 8)

2.3.2 Alao division

From west to east the Alao division consists of the following subdivisions: Peltetec (ocean floor; Pacheco; Maguazo (fore-arc turbidites and andesites); Alao-Paute (andesitic volcanic arc); and El Pan (volcano-sedimentary unit, ?back-arc). The regional distribution of the Alao division is given in Litherland et al. (1990) and in previous Annual Reports (see also Maps 8 and 9 in this report). Its eastern limit corresponds to the Baños front (Table 1).

2.3.2.1 Peltetec subdivision: Thin sections of samples collected from the Peltetec subdivision have been examined by Dr. Fortey (Appendix 4b). Although only a limited number of specimens were available for study (26 in all). Dr. Fortey's findings, that these rocks form a consistent set of ophiolitically related lithologies, are in keeping with our earlier interpretation that the Peltetec subdivision is a dismembered ophiolite.

Amongst other rock types identified are the following: serpentinites, variously altered gabbros, possible norite, pyroxenite, altered basalts and dolerite. The juxtaposition of plutonic and "high-level" rocks, the variation in alteration and development of schistosity are consistent with suggestions that this subdivision represents a tectonic mélange.

2.3.2.2 Pacheco subdivision: These rocks are present only in the north (Map 8) and form the eastern part of what was previously referred to as the Ambuquí schist inlier (Baldock, 1982). The Pacheco subdivision is not well known but is thought to consist principally of basaltic greenstones which are in tectonic contact with the Ambuquí subdivision to the west (see 2.3.1). The status of these rocks is uncertain but they are tentatively correlated with either the Peltetec or Maguazo subdivisions to the south.

2.3.2.3 Maguazo subdivision: As noted in Litherland (1989) (Appendix 9), float samples collected from the Río Jadán yielded Callovian-Oxfordian palynomorphs. In an attempt to confirm this age nine samples of 'in situ' black and grey phyllites from the Maguazo subdivision, which is exposed along the main road from Cuenca to Paute, were submitted for palynological analyses (see Dr. J. B. Riding's report, Appendix 5a). Unfortunately, no diagnostic palynomorphs were found but a broad Jurassic/Cretaceous age was indicated.

2.3.2.4 Alao-Paute subdivision: Typically, this subdivision consists of andesitic greenstones and greenschists. Meta-agglomerates are relatively common, especially in the south near Gualaceo. Minor amounts of metasediments, phyllites and probable meta-tuffaceous material, are also present.

The major outcrops of the Alao-Paute subdivision are located along the western flank of the Cordillera Real between approximately 1°S - 3°S (Map 9). In the field it can be demonstrated that the development of greenschists is normally related to the presence of generally steep to vertical, Andean, trending shear zones but that away from these areas the rocks are often massive and relatively undeformed.

Geochronology of the Alao-Paute subdivision

Radiometric age determinations obtained from the Alao-Paute subdivision are considered to be unreliable due to the very low potassium content of the separated minerals (Appendix 8, in Litherland, 1989).

2.3.2.5 El Pan subdivision: This subdivision is present in the southern part of the Alao-Paute division (Map 9) and in broad terms it corresponds to the western part of the El Pan schists of Bristow and Guevara (1980) and Bristow et al. (1975) (see also Baldock, 1982). It is essentially a mixed volcano-sedimentary unit which contains a variety of both schistose and phyllitic rocks. Feldspathic (sericitic) phyllites, graphitic phyllites and more massive actinolitic $\pm$ clinozoisite $\pm$ epidote-bearing greenstones are common. Impure quartzites and dark coloured marbles are also present. In general, it appears that this unit is of a slightly higher metamorphic grade than is common elsewhere in the Alao division.

2.3.3 Loja division

The Loja division, the western limit of which coincides with the Baños front, comprises five principal subdivisions (Table 1). Details of the Tres Lagunas, Chigüinda, Sabanilla and the Agoyán subdivisions have been given in previous Annual Reports and a regional synthesis appears in Litherland et al (1990). Additional information collected during the past 12 months is discussed below.

2.3.3.1 Tres Lagunas subdivision: This subdivision consists of biotite granites which outcrop close to, or immediately to the west of, the Baños front (Map 9). The granites are extensively sheared and commonly comprise S-C, Type I mylonites (Berthe et al., 1979; Lister and Snoke, 1984). Chemically and mineralogically these rocks exhibit certain characteristics of S-type, crustally derived granites. New petrological descriptions of granites/monzogranites from the Papallacta and Oyacachi area (Map 1, in Litherland, 1989) and the Monte Olivo pegmatite belt (Map 8, this report), believed to represent the northern extension of the Tres Lagunas subdivision, are given in Appendix 4b.

Geochemistry of the Tres Lagunas subdivision

Eighteen whole-rock, major and trace element analyses from the Tres Lagunas subdivision are listed in Appendix 3. Detailed plots of the data still have to be completed but a brief examination of these results confirms our earlier field observations that the rocks are compositionally restricted. With the exception of SH14K, which represents an aplitic xenolith within the main Tres Lagunas granite, major elements have the following ranges: SiO₂ 68-73 wt%; Al₂O₃ 13-14 wt%; CaO 1.5-2.5 wt%; Na₂O 2-3 wt% and K₂O 3-4 wt%.

One of the simpler plots used to distinguish between S- and I-type granites is that of K₂O versus Na₂O (Chapell and White, 1974). In Fig. 2 the K₂O and Na₂O analyses obtained from the Tres Lagunas subdivision and also from the Zamora, Abitagua and Azafrán calc-alkaline batholiths (Appendix 3) have been plotted. As can be seen the latter group falls within the I-type field whereas the Tres Lagunas samples, with the exception of one point, lie within, but close to the limit of, the S-type field. This plot appears to characterise the granites of the Tres Lagunas subdivision and to set them apart from the I-type batholiths of the Ecuadorian Andes.

In addition to the above ⁸⁷Sr/⁸⁶Sr ratios obtained from whole-rock analyses give values >0.712. These initial ratios are based on 'errorchrons' (see below and also Appendix 2b) and so may not be entirely reliable. However, they do suggest substantial crustal contamination of the Tres Lagunas magmas and contrast with the lower initial ratios of 0.7046 obtained from the Abitagua batholith (Appendix 3, in Litherland, 1988).

Geochronology of the Tres Lagunas subdivision

Throughout the project various attempts have been made to date the Tres Lagunas subdivision but none of the methods employed (K-Ar, Rb-Sr (whole-rock) and Sm-Nd (garnet)) have proved to be entirely successful.

A single Sm-Nd (garnet) isochron gave an age of 257 ± 125 Ma and Rb-Sr whole-rock 'errorchrons' from the Malacatus basin and from the Tres Lagunas area to the east of Saraguro gave ages of 194 ± 50 Ma (MSWD = 49.5) and 189 ± 43 Ma (MSWD = 289.1) (Appendix 2b). The combined Rb-Sr data (18 points) give an 'errorchron' age of 200 ± 12 Ma (MSWD = 169.1) (Fig. 7c, Appendix 2b).

The interpretation of these results is not simple, but they suggest that the Tres Lagunas subdivision could be of Early Jurassic/Late Triassic age. It may be significant that this age is similar to, but slightly younger than, that obtained from garnet-bearing paragneisses and pegmatitic gneisses from the La Bocana area in El Oro (Appendix 2b Fig. 3, and Table 4, samples 6B, 6C, 6D and 7A). If so, it could suggest a genetic link between the two areas (i.e. that perhaps El Oro was once part of the Cordillera Real!).

In addition to the above, various younger discordant (muscovite and biotite) K-Ar mineral ages have been obtained from the Tres Lagunas subdivision, and these are discussed in Section 2.6.

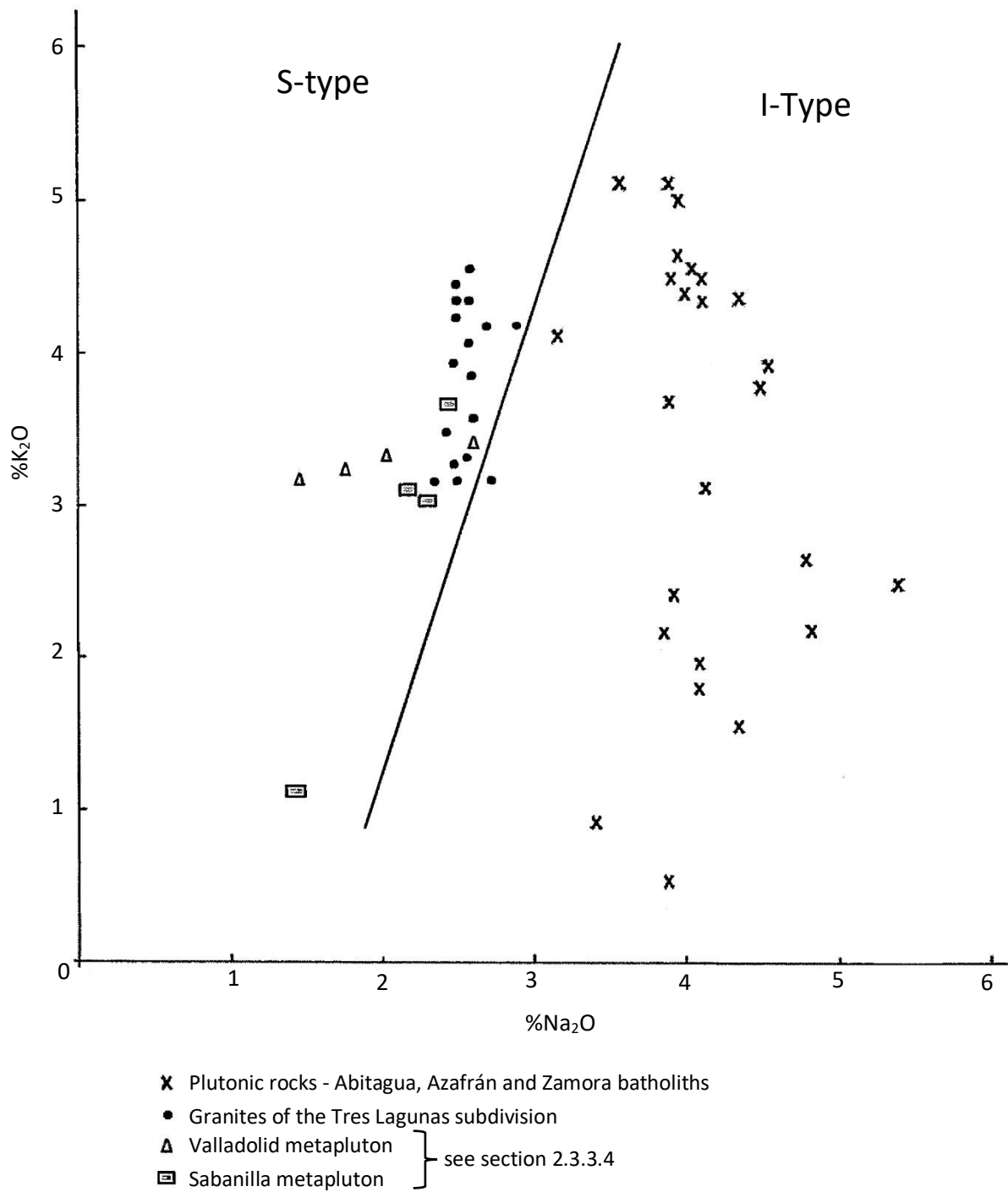


Figure 2. Comparison of K₂O y Na₂O values of the Tres Lagunas subdivision and the Abitagua, Azafrán and Zamora batholiths

2.3.3.2 Agoyán subdivision: This subdivision consists essentially of paragneisses and schists which are often intimately related to the Tres Lagunas subdivision. Garnet and muscovite $\pm$ chlorite $\pm$ biotite are commonly present. In the south (Map 9) this unit is well exposed immediately to the west of Baños along the Puyo road where it includes minor amphibolites. It is also present in the Upano valley near to Zuñac (Appendix 1f, Map 5) where garnetiferous schistose and gneissic rocks are present, some of which carry post-kinematic albite.

In the north (Map 8), near Monte Olivo, the Agoyán subdivision can be divided into a mapable garnet muscovite paragneiss unit in the east and in the west a schistose unit which includes quartzites and metapsammites that contain thin 'veins' (10 cm across) of carbonated serpentinite with apple green Fe^{2+} -fuchsite (see Chapter 3). These latter rocks are intercalated, possibly tectonically, with the basaltic amphibolites of the Monte Olivo subdivision (Appendix 1b and Map 1). Along the western margin of the gneissic unit, granite-pegmatite zones which contain tourmaline, muscovite $\pm$ zoisite $\pm$ rutile occur. These are tentatively correlated with the Tres Lagunas subdivision (Map 8) and samples collected from this belt are described by Dr. Fortey (Appendix 4b).

2.3.3.3 Chigüinda subdivision: This was formerly referred to as the Loja semi-pelite division and it occurs extensively in the southern part of the Cordillera Real. To the north of the Gualaceo-Plan del Milagro road it is replaced along strike by the Salado division (see Map 9) but the precise age and structural relationships between these units remain enigmatic.

Field observations made along the western margin of the Zamora batholith (Appendix 1e, Map 4) suggest that the Chigüinda subdivision is intruded by this early to late Jurassic pluton. However, poorly preserved palynomorphs may indicate a somewhat younger 'broad Jurassic/Cretaceous' age (Appendix 5b).

The division consists dominantly of semi-pelitic rocks but also includes pale green, possibly tuffaceous horizons and minor greenstones (Appendix 1d, Map 3, Jimbilla-Río Quimi traverse).

2.3.3.4 Sabanilla subdivision: This subdivision has only been recognised in the extreme south east of the Cordillera Real (see Map 8, in Litherland 1989) and is a complex unit which comprises principally of orthogneiss but also includes zones of migmatites, paragneisses, amphibolites and muscovite $\pm$ biotite pegmatites. The metamorphic grade of the unit varies from medium to high grade, garnets are widespread but staurolite is present and some paragneisses carry sillimanite and/or kyanite (Appendix 4a, FV-44, FV-45).

Geochemistry of the orthogneisses of the Sabanilla subdivision

Eight whole-rock analyses from two metaplutons in the Sabanilla subdivision are listed in Appendix 3. The Valladolid metapluton (orthogneiss) is located to the north of Valladolid along the main road to Yangana in the area of Quebrada Honda. The Sabanilla metapluton (in part migmatitic) outcrops along the west bank of the Río Zamora to the north of Quebrada La Rábida (Map 8, in Litherland, 1989).

As can be seen from the analyses these plutons are rich in SiO₂ (>71 wt%) but compositionally they appear to be somewhat more variable than those of the Tres Lagunas subdivision. In spite of this variation and also their different field aspect, when these analyses are plotted in Fig. 2 they fall within the S-type field suggesting a possible genetic link between these two subdivisions.

Initial ratios (⁸⁷Sr/⁸⁶Sr) obtained from these plutons (see also Appendix 3, in Litherland, 1988) although based in 'errorchrons' (see below), range from 0.7088 for the Valladolid metapluton to 0.711 for the Sabanilla metapluton and would suggest that crustal contamination was an important factor in their genesis.

Geochronology of the Sabanilla subdivision

Various attempts to date the Sabanilla subdivision have been made using K-Ar, Rb-Sr (whole-rock) and Sm-Nd (garnet) methods. Without exception the K-Ar results obtained are considered to be disturbed and these will be discussed further in Section 2.6. Equally the Sm-Nd and Rb-Sr results obtained from samples collected from the Valladolid area proved to be unsatisfactory (Appendix 2b).

Although no Rb-Sr isochron ages have been obtained from the Sabanilla metapluton the following 'errorchron' ages (Appendix 2b, this report; Appendix 3, 1988) of 198 ± 45 Ma (MSWD = 25.3); 233 ± 51 Ma (MSWD = 175.4) and 234 ± 19 Ma (MSWD = 20.6) and 224 ± 37 Ma (MSWD = 108.6, combined dates from Rundle and Harrison, 18 points) do have a certain consistency and suggest that these rocks were affected by an important thermal event ca. 220 Ma ago.

2.3.3.5 Monte Olivo subdivision: This subdivision is present only in the north of the Cordillera Real (Map 8) and consists of basaltic amphibolites. Field evidence suggests that these are intercalated, possibly tectonically, with a packet of metapsammitic rocks of the Agoyán subdivision.

2.3.4 Salado division

This division consists of foliated, calc-alkaline batholiths and a metavolcano-sedimentary sequence. It is especially widespread in the northern part of the Cordillera Real from the Colombian border to ca. 3°S. Southwards it is apparently replaced by the dominantly pelitic/semipelitic Chigüinda subdivision.

2.3.4.1 Santa Bárbara subdivision: This subdivision is restricted to the north east of the Cordillera, near to the Colombian border (Map 8). It consists of medium to fine-grained biotite ± hornblende gneisses which are banded in places and possibly represent metamorphosed calcic tuffs.

2.3.4.2 Azafrán subdivision: This subdivision comprises foliated calc-alkaline plutons, it includes the Azafrán batholith, which is exposed along the Baños-Puyo road (Map 9), the Chingual/Sacha plutons, and possibly the Condué granite near to the Colombian frontier (Map 8).

Geochemistry of the Azafrán subdivision

Six whole-rock analyses obtained from the Azafrán batholith (Baños road section) are listed in Appendix 3. Although based on the $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios these samples are probably true granites (monzogranites?), field observations suggest that the subdivision is dominated by biotite $\pm$ hornblende granodiorite which frequently contains mafic and also which schistose xenoliths. Diorites, gabbros and hornblendites are also present.

Geochronology of the Azafrán subdivision

Attempts to date the Chingual pluton (orthogneiss) and the Azafrán batholith have not been entirely successful, Rb/Sr 'errorchron' ages obtained for Chingual (Appendix 3, in Litherland, 1988) gave 146 ± 58 Ma (MSWD = 8.2) and, omitting the two most obvious outlying points 156 ± 21 (MSWD = 2.8). In contrast, a 7-point isochron obtained from the Azafrán batholith gave an age of 120 ± 5 Ma (MSWD = 2.4); $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios obtained from these plutons varied from 0.7037 (Chingual) to 0.7067 (Azafrán).

In spite of the fact that an isochron was obtained from the Azafrán batholith this age is not entirely satisfactory since elsewhere in the Cordillera, and also to the north in Colombia (Aspden et al., 1987), large calc-alkaline batholiths of this age are unknown. Added to this is the fact that further to the west along the Baños road, in the Río Verde, two samples of hornblende biotite diorites collected from outcrop gave K/Ar ages of: 128 ± 4 Ma (Hb) 125 ± 4 Ma (Bt) and 175 ± 5 Ma (Hb) 176 ± 5 Ma (Bt) (see samples 10A and 10B Appendix 8, in Litherland, 1989). In addition, a float sample of hornblendite from the Río Verde yielded a K/Ar date of 171 ± 5 Ma (Hb) (see sample ADML1, Appendix 4, in Litherland, 1987).

Taking the K/Ar data together it appears that the R. Verde rocks, which we interpret as part of the Azafrán batholith, are recording an older (i.e. ca. 170 Ma) event and a younger (i.e. ca. 128 Ma) event. Samples 10A and 10B were collected only a few metres apart but re-examination of this site made it clear that 10A came from a zone affected by shearing whereas 10B was apparently massive and no sign of alteration could be detected in either the hornblende or biotite in hand specimen. Based on these observations it seems reasonable to conclude that the older age obtained from the Río Verde could be a magmatic age whereas the younger date is reset and probably relates to a shearing event which affected the Azafrán batholith.

Provided that these deductions are correct then it follows that the 120 ± 5 Ma isochron age obtained for the Azafrán batholith is not a true magmatic age and that it too was reset by the regional shearing event. In an attempt to confirm this hypothesis more detailed geochronological studies need to be carried out. A sample for zircon dating was collected from the Azafrán batholith but unfortunately this remains to be processed.

2.3.4.3 Upano subdivision: This subdivision is named after the rocks which are exposed along the unsurfaced track which leads westwards from Macas and follows the lower reaches of the Río Upano (Appendix 1f, Map 5 and Map 9). It consists of a mixed metavolcano-sedimentary sequence which includes metalavas, metavolcanoclastics (metatuffs and agglomerates), metagreywackes and minor marbles. Impure quartzites and black phyllites $\pm$ graphite are also present. Typically, the subdivision consists of greenschists but may also include some amphibolites. It is assumed, but not proven, that these rocks are the age equivalents of the metaplutonic rocks of the Salado division (i.e. Jurassic) but an older age cannot be ruled out.

2.3.4.4 Cerro Hermoso subdivision: The characteristics of the Cerro Hermoso sequence, after which this subdivision has been named, are given in Litherland (1988, p. 19) (see also Litherland et al., 1990). These rocks are geographically restricted and in the present report are confined to a narrow fault-bounded belt of black pyritic phyllites which occurs to the west of Baños between the Agoyán and Azafrán subdivision (Map 9).

2.3.5 Zamora division

This division is essentially non-foliated and occurs towards the western edge of what is considered to be the approximate limit of the Amazonian craton. It consists principally of major, late Early Jurassic-Late Jurassic calc-alkaline batholiths (Abitagua subdivision), and what is considered to represent their volcanic equivalents (Misahuallí subdivision). In the southeast also includes a belt of low-grade metamorphic rocks which are intruded by, and occur as large rafts within, the Zamora/Río Mayo batholith (Isimanchi subdivision) (Litherland et al., 1990; Map 8 in Litherland, 1989). These latter rocks are not discussed further in this report.

2.3.5.1 Abitagua subdivision: This comprises major, non-foliated, calc-alkaline batholiths which from north to south include the La Bonita and Rosa Florida batholiths (Map 8), the Abitagua batholith (Baldock, 1982 and Map 9) and the Zamora/Río Mayo batholith (Map 8, in Litherland, 1989).

Geochemistry of the Abitagua subdivision

Field observations indicate that these batholiths show a range of compositions typical of calc-alkaline batholiths. Although true granites and possibly even syenites and gabbros do occur, biotite $\pm$ hornblende granodiorites and quartz monzodiorites/diorites tend to be dominant. In Appendix 3, 19 whole-rock analyses from the Abitagua and the Zamora batholiths are listed (see also Fig. 2).

Geochronology of the Abitagua subdivision

Prior to the Cordillera Real Project relatively few age determinations were available for the plutonic rocks of the Abitagua subdivision.

Kennerley (1980) reported three K/Ar mineral ages of 152 ± 4 Ma (K-spar), 173 ± 5 Ma (hornblende) and 130 ± 5 Ma (biotite) for a single sample from the Río Mayo batholith (now considered to be part of the Zamora batholith). Also, Aly (1980) obtained a K/Ar age of 171 ± 6 Ma from the Zamora batholith. A three-point whole-rock Rb-Sr isochron age of 173 ± 5 Ma was obtained by Halpern (quoted in Hall and Calle, 1982) for the Abitagua batholith and a K/Ar (biotite) age of 178 ± 7 Ma was reported by Herbert (1977). In addition, Kennerley quotes a younger K/Ar (biotite) date of 87 ± 7 Ma which was obtained for a sample collected from the southern end of the Abitagua batholith along the Baños-Puyo road.

During the project various plutonic rocks from the Zamora and Abitagua batholiths have been dated. Rb/Sr whole-rock isochron ages obtained from the Abitagua batholith gave the following dates: 161 ± 2 Ma (MSWD = 0.9) (9 points); 163 ± 2 Ma (MSWD = 2.5) (7 points) and 162 ± 1 Ma (MSWD = 2.5) (combined data, 16 points) (see Appendix 3, in Litherland, 1988). Initial ratio intercepts for these isochrons ($^{87}\text{Sr}/^{86}\text{Sr}$) range from 0.7046 ± 4 to 0.70459 ± 3 and are typical of those values associated with I-type, subduction zone magmas. Several K/Ar mineral determinations have also been carried out on samples from the Abitagua batholith. However, the mafic phases, in particular the biotites, were often chloritised and hence yielded younger ages when compared with the Rb/Sr results. In spite of this, sample 6A gave duplicate K/Ar (Hb) dates of 152 ± 7 Ma and 164 ± 10 Ma but significantly younger biotite ages of 125 ± 12 Ma and 128 ± 9 Ma (Appendix 8, in Litherland, 1989). In addition, a float block collected from the Río Zúñag, which drains the Abitagua batholith in the south, gave a K/Ar (hornblende) age of 171 ± 5 Ma (Appendix 4, in Litherland, 1987).

In contrast with the Abitagua batholith, where the Rb/Sr whole-rock method was extremely successful, the analyses obtained from the Zamora batholith failed to produce an isochron (Appendix 3, in Litherland, 1988). In spite of this a large number of K/Ar mineral ages have been obtained from this batholith and these are listed in Table 2. As can be seen, several of the samples yield concordant hornblende and biotite mineral ages and since the pluton is undeformed these are taken to represent magmatic cooling ages. The exceptions to this general observation are samples RM1 and 20 which yield discordant hornblende/biotite ages of 132 ± 5 Ma (Hb); 104 ± 3 Ma (Bt) and 126.5 ± 4 (Hb); 168.5 ± 5 (Bt), respectively, and sample 16C which gives a young age, albeit with a high error of 134 ± 21 Ma (Table 2). All the plutonic ages obtained by the project from the Abitagua and Zamora batholiths have been plotted in simple histogram form in Fig. 3. Based on these data it is concluded that the age of these plutons ranges from latest Early Jurassic to Late Jurassic and that major plutonism ceased at ca. 150 Ma (see Table 2). The younger ages of between 125-135 Ma and 95-105 Ma are considered to be disturbed and are referred to later in section 2.6.

2.3.5.2 Misahuallí subdivision: This subdivision consists of a continental sequence of non-foliated lavas, which includes andesites, dacites, rhyolites, basalts, tuffs and agglomerates, and is interpreted to represent the volcanic products of the plutonic Abitagua subdivision. In the north, field evidence suggests that there is a lithological transition across the sub-Andean zone into the deformed, marine volcano-sedimentary Upano subdivision which, at least in part, is thought to represent its western lateral facies equivalent (Map 8).

To the south and east however, there is evidence, along the new road which runs from Méndez to Santiago, that the Santiago Fm. is in fact interbedded with turbiditic tuffaceous sediments which have been previously assigned to the Chapiza Fm. (Tschoopp, 1953). This observation indicates that during Santiago deposition (Sinemurian time) and prior to the intrusion of the Abitagua subdivision, volcanic activity was widespread in this part of Ecuador. It is entirely possible therefore that the Misahuallí subdivision (and therefore by analogy the Upano subdivision) includes both pre-and syn-Abitagua subdivision elements.

Geochronology of the Misahuallí subdivision

Few radiometric age determinations are available for the Misahuallí subdivision. Indirect evidence for its age comes from K/Ar mineral dates obtained from two cross-cutting hornblende andesitic dikes in the Abitagua and Zamora batholiths; sample 7 gave duplicate ages of 168 ± 4 Ma and 174 ± 8 Ma and sample 25 gave 143 ± 7 Ma, a float sample of a porphyritic hornblende andesite, collected from the Quebrada Curishpe, which drains the western part of the Zamora batholith to the south of La Paz, (see Map 8, in Litherland, 1989), gave duplicate hornblende ages of 230 ± 14 Ma and 214 ± 23 Ma (see Appendix 8, in Litherland, 1989). A whole-rock K/Ar age of 72 ± 9 Ma has also been obtained for andesites which outcrop to the SE of Zumba near to Quebrada San Francisco and the Peruvian border (see Map 8, in Litherland, 1989, and Appendix 2c of this report, sample 18).

Interpretation of the above data is somewhat difficult since the sampling points are so few and widely scattered. As a general comment however, it can be seen in the area of Quebrada San Francisco that the volcanics are overlain by the Early Cretaceous Hollín Fm. hence, while the possibility of Late Cretaceous volcanism cannot be ruled out, it is unlikely that it was widespread in this zone.

Table 2. Zamora/Río Mayo batholith K-Ar mineral ages for plutonic rocks

Sample No.	Mineral	%K $\pm$ % <i>Sd</i>	Atm 40 Ar %	Rad 40 Ar $\pm$ % <i>Sd</i> (nl/g)	Age $\pm$ 2 <i>Sd</i> (Ma)
FV-60	Hb	0.570	35.7	3.49	151 $\pm$ 5
16-C	Hb	0.371 $\pm$ 1.0	88.5	2.009 $\pm$ 8.1	134 $\pm$ 21
16-H	Hb	0.289 $\pm$ 1.0	71.8	2.107 $\pm$ 2.8	178 $\pm$ 10
17	Hb	0.227 $\pm$ 2.4	40.6	1.776 $\pm$ 1.5	191 $\pm$ 10
19	Hb	0.205 $\pm$ 1.0	50.2	1.581 $\pm$ 1.5	188 $\pm$ 6
20	Hb	0.591 $\pm$ 1.0	40.1 *	4.356 $\pm$ 1.2	126 $\pm$ 4
			18.5 *	4.398 $\pm$ 1.0	127 $\pm$ 4
	Bt	2.34 $\pm$ 1.0	37.3 *	15.77 $\pm$ 1.2	166 $\pm$ 5
			38.0 *	16.35 $\pm$ 1.2	171 $\pm$ 5
21-A	Hb	0.99 $\pm$ 2.8	64.0	6.134 $\pm$ 2.2	153 $\pm$ 10
	Bt	3.93 $\pm$ 1.0	25.7	24.32 $\pm$ 1.1	153 $\pm$ 4
21-G	Hb	0.971 $\pm$ 4.0	45.6	6.036 $\pm$ 1.3	153 $\pm$ 12
	Bt	5.16 $\pm$ 1.0	25.3	32.78 $\pm$ 1.1	156 $\pm$ 5
22-B	Bt	4.70 $\pm$ 1.0	20.8	34.20 $\pm$ 1.1	178 $\pm$ 5
22-E	Hb	0.32 $\pm$ 2.0	64.2	2.363 $\pm$ 3.3	181 $\pm$ 14
13-A	Hb	0.17	63.96	1.331	193 $\pm$ 9
13-B	Hb	0.16	81.95	1.230	187 $\pm$ 17
RM-1	Hb	0.593	59.3	3.161 $\pm$ 1.8	132 $\pm$ 5
	Bt	4.64	15.9	19.29 $\pm$ 1.0	104 $\pm$ 3
485	Hb	0.481	37.6	3.247 $\pm$ 1.2	166 $\pm$ 5
	Bt	4.04	52.0	28.73 $\pm$ 1.5	174 $\pm$ 6
681	Hb	0.916	22.5	5.708 $\pm$ 1.0	153 $\pm$ 5
	Bt	5.67	23.5	34.53 $\pm$ 1.1	150 $\pm$ 4
26-B	Hb	0.499 $\pm$ 1.0	78.8	3.562 $\pm$ 3.9	175 $\pm$ 14
	Bt	4.19 $\pm$ 1.0	24.1	29.34 $\pm$ 1.1	172 $\pm$ 5
26-C	Hb	0.549 $\pm$ 1.0	78.6	4.172 $\pm$ 3.9	186 $\pm$ 14
	Bt	5.21 $\pm$ 1.2	38.7	39.87 $\pm$ 1.2	187 $\pm$ 6
26-E	Hb	0.375 $\pm$ 1.0	78.0	2.688 $\pm$ 3.8	176 $\pm$ 13
	Bt	2.13 $\pm$ 1.0	34.1	15.53 $\pm$ 1.1	178 $\pm$ 5

* Repeat analyses

Hb = Hornblende; Bt = Biotite

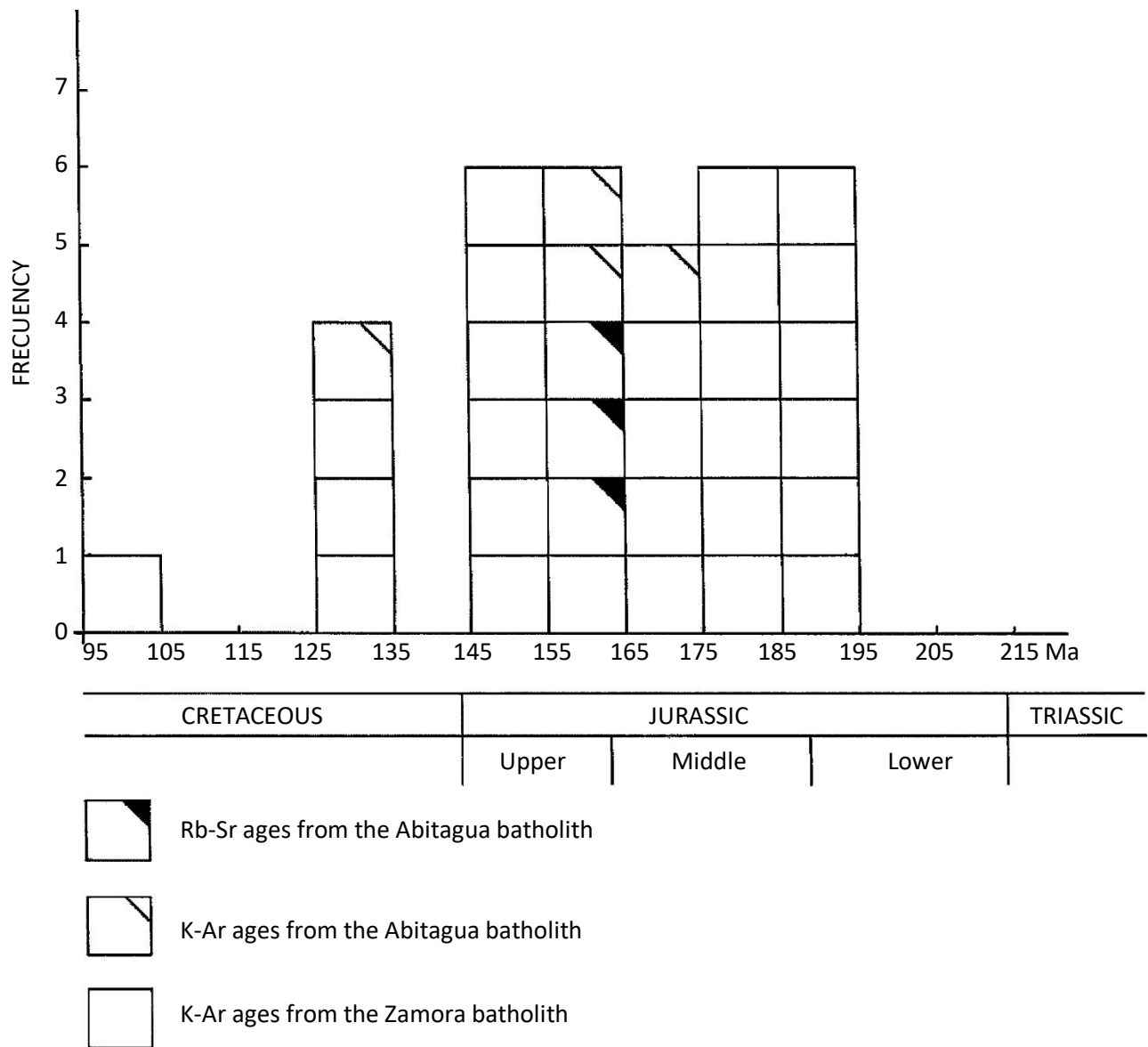


Figure 3. Radiometric age determinations (K-Ar and Rb-Sr) of plutonic rocks from the Abitagua and Zamora batholiths

2.4 Geology of the Cretaceous rocks of the Cordillera Real

2.4.1 Cretaceous sediments: Hollín, Napo and Tena Formations

These Formations are restricted to the eastern slopes of the Cordillera Real and full lithological descriptions are given by Tschopp (1953) and Baldock (1982).

In the north (Map 3) these rocks occur to the east of the Rosa Florida fault and in the Río Cofanes the Napo Fm. is overthrust to the east above the younger (Maastrichtian-?Lower Palaeocene) Tena Fm.

Further to the south Napo/Hollín duplexes are well-exposed to the west of Sucúa along the Río Tutanangoza (Map 9). Approximately two kilometres to the east of the Río Nayanbayne, in a more or less continuous 50-70 m outcrop, up to five repetitions of Hollín sandstone, which structurally lies above the black shales of the Napo Fm., can be seen (Appendix 1j and Map 7). This thrusting is also thought to involve the Tena Fm. but until good palaeontological control is obtained the presence of older rocks cannot be ruled out.

Further to the west, along the same river, another poorly exposed Hollín/Napo duplex outcrops. Significantly these rocks are only moderately deformed and weakly metamorphosed. However, they are separated from the more easterly Cretaceous outcrop by a narrow 2-3 km thrust slice of strongly deformed (mylonitic) greenschists of the Upano subdivision. This observation argues strongly that a regional pre-Hollín metamorphic/tectonic event affected the Cordillera Real. It contradicts views expressed by Feininger (1975, 1982) that the principal metamorphic event occurred during the late Cretaceous period and that the protolith represented lateral (westerly) equivalents of the Hollín and Napo Formations.

Immediately to the north of the Río Tutanangoza a complex pattern of repetitions of Hollín and (?) Tena outcrops have been mapped in the Río Miriumi and Río Cuyataza by P. Townsend of BP Development Ltd. (see also Map 9). In this area it appears that the Hollín Fm. is overthrust eastwards above the Tena Fm. but that this contact was later folded by deeper level thrusts which were still being generated in the sub-Andean zone (Townsend, pers. comm.).

In the east of the Río Upano section, to the west of Macas, a narrow strip of Napo Fm. is shown on Map 9. It should be noted that on the recently published 1:100000 Geological Map of Macas (Lascano et al., 1989) this is included within the Abanico Formation. However, based on lithological correlation and the fact that the grade of metamorphism of these rocks is very low when compared to that of the Upano subdivision immediately to the west, we prefer to include them in the Napo Fm.

2.4.2 Cretaceous intrusives and mafic complexes

Relatively few intrusives of this age are present within the Cordillera Real.

2.4.2.1 Pimampiro pluton: The Pimampiro pluton, which is faulted along its eastern margin, consists of flow-banded, hornblende porphyritic biotite granodiorite. The following K/Ar mineral ages have been obtained from the intrusion: sample 1A 80 ± 4.5 Ma (Hb) and 84 ± 3 Ma (Bt); sample 1C 92.5 ± 3.5 Ma (Hb) and 73 ± 3 Ma (Bt) (Appendix 8, in Litherland, 1989).

In addition, Evernden (1961) reported a K/Ar age of 72 Ma from Pimampiro. These dates indicate a late Cretaceous age for the pluton but suggest that it has possibly been affected by a later thermal overprinting which would account for the discordant, younger biotite age recorded from sample 1C. (N.B. sample 1B in Appendix 8 is a float sample of muscovite pegmatite collected from the Río Chota. It is thought to have been derived from the Tres Lagunas subdivision (Lt in Map 8). The K/Ar age of 60 ± 2 Ma (Musc) is considered to be reset).

2.4.2.2 Magtayán area: This area has not been studied in detail by the project but it appears that both granodioritic to tonalite plutons and also mafic/ultramafic, hornblende-rich bodies may be present (Sosa et al., 1975; Kennerley, 1980; D. Benalcazar, pers comm).

During 1987 the Magtayán area was visited by the project and various float samples were collected for K/Ar analysis. Samples 13A and 13C consisted of hornblende $\pm$ biotite tonalite/diorites and are assumed to have been derived from the Magtayán pluton, whereas 13B a pegmatitic hornblende gabbro, may have been derived from the mafic hornblende-rich bodies which, according to D. Benalcazar (pers. comm.), also outcrop in the area (Map 9). Obviously more detailed sampling of actual outcrops needs to be carried out but if the above inferences are correct then the Magtayán pluton is probably Late Cretaceous, since samples 13A and 13C yielded ages of 74 ± 3 Ma (Hb) and 68 ± 5 Ma (Bt) and 79 ± 3 Ma (Hb). The pegmatitic hornblende gabbro (13B) also gave a Late Cretaceous, but a slightly older, 87.5 ± 4.5 Ma date (Appendix 8, in Litherland, 1989), which is in broad agreement with that reported by Kennerley (1980) of 85 ± 3 Ma for hornblendite from the Magtayán area.

2.4.2.3 Tampanchi mafic/ultramafic complex: Mafic/ultramafic complexes within the Alao-Paute subdivision were first recognised in the Tampanchi area to the east of Azogues (see Litherland, 1988, p. 12 and 1989, p. 5). Twenty-one thin sections of rocks collected from this complex have been examined by Dr. Fortey and his findings are included in Appendix 4b. Two whole-rock analyses of samples collected from the Tampanchi complex are listed in Appendix 3.

In addition to petrological studies, three K/Ar ages were obtained from the complex by Dr. Harrison (Appendix 2b). Samples 17A and 17B, which consisted of hornblende gabbro and a pegmatitic hornblende/plagioclase facies, yielded mineral ages of 65.7 ± 3 Ma and 61.2 ± 4 Ma respectively and sample 17C, a fine grained, hornblende-rich basalt, gave a whole-rock age of 60.6 ± 10 Ma. According to Dr. Fortey, the Tampanchi complex is unmetamorphosed and relatively undeformed and hence these dates are likely to reflect magmatic cooling ages. They are however, significantly younger (ca. 25 Ma) than those recorded from the Magtayán area (Section 2.4.2b).

2.4.2.4 Other mafic/ultramafic complexes: Hornblendites and/or gabbros, very similar to those of Tampanchi, outcrop near to the small village of El Azul and also occur in float blocks in two small unnamed south bank tributaries of the Río Upano, to the west of Zúñag (Map 9). Hornblendite and gabbro boulders are also present to the west of Paute above the village of Shumir, in the area around 7450-9692 (Azogues 1:50000 topographic sheet, L. Quevedo, pers. comm.).

The apparent restriction of these complexes to the Alao-Paute subdivision and their ultimate origin remains uncertain.

2.4.3 Tertiary sediments

Two tertiary sedimentary units are shown on Map 9. The Miocene Arajuno Fm., which is restricted to the Oriente, has been described by Tschopp (1953) and subsequently by Mortimer et al. (1980). According to these latter authors it is in fault contact with, but structurally lies below, the Tena Fm. to the west.

The Atillo sandstone, located near to the Laguna Atillo (Map 9), has not been previously recognised. It consists of a sequence of fluvial channel sandstones and siltstones that contain carbonaceous-rich horizons. A well-preserved fish fossil was discovered in this sequence and a full report by Dr. Patterson on this find is included as Appendix 5c. The precise age of the Atillo sandstone is still in doubt but since, as pointed out by Dr. Patterson, similar taxa have been described from the Miocene Loyola and Mangán Fms. in the Cuenca basin to the south (Bristow, 1973; Roberts, 1975) then a Miocene age would seem to be most probable.

2.4.4 Lower Tertiary intrusives

Throughout much of the Cordillera Real a number of undeformed, post-tectonic stocks and plutons of principally granodiorite composition have been identified (see previous Annual Reports and Litherland et al., 1990). In the area covered by Map 9 three such plutons have been dated: Pungalá (45 ± 4 Ma, 42 ± 2 Ma, Appendix 8, in Litherland, 1989) the small unnamed stock along the Gualaceo-Plan de Milagro road (39 ± 4 Ma, Appendix 4, FV-83, in Litherland, 1987) and the Amaluza pluton (34 ± 1 , 49 ± 2 Ma, Kennerley 1980; Herbert and Pichler, 1983).

The Salado pluton (Map 9) has not been dated but since it is apparently undeformed it is assumed to be Lower Tertiary. An older age cannot however be entirely ruled out.

In the north (Map 8) the Azuela pluton may also be of this age.

2.4.5 Porphyry stocks

A number of small, undeformed, high-level, porphyry stocks are present near to the Baños front in the southern part of Map 9. The ages of these intrusions are not known but most probably they are Late Tertiary.

2.4.6 Cenozoic volcanic deposits

These deposits are widespread especially along the western flanks of the Cordillera Real. They include tuffs, lavas, agglomerates and the principle volcanic centres of Tungurahua, Altar and Sangay. Several small volcanic necks are also indicated on Map 9 in the south.

These deposits have not been studied by the project but regionally it is of interest to note that Tungurahua, Altar and Sangay are spatially related to the Baños front (Map 9).

2.5 Structure

A general structural cross-section of the Cordillera Real was presented in Litherland (1989) (Fig. 2) but detailed studies still remain to be completed.

The occurrence of 'horses' (in the sense of Butler, 1983), fault-bounded lenses, and the alternation of flat and steep belts of cleavage would seem to be consistent with an imbricate thrust stack model. However, it is also apparent that S-C type 1 mylonites (Lister and Snoke, 1984) are widespread within the major plutonic subdivisions of the Cordillera Real (e.g. Azafrán and Tres Lagunas). Also, observations that mineral lineations, for example within the Azafrán subdivision along the Baños road, are generally either sub-horizontal or have gentle to moderate, often southerly plunges, would suggest that transpression has been an important factor in Cordilleran deformation. Preliminary thin section evidence indicates that movements were essentially dextral.

In contrast, along the Baños front to the south of Sigsig, westerly to north westerly plunging lineations and asymmetric augen structures provide good evidence for 'simple compression' and the overthrusting of the Alao-Paute subdivision from the WNW over the Tres Lagunas subdivision to the ESE.

2.6 Disturbed radiometric ages from the Cordillera Real

Throughout Section 2 attempts have been made to summarise the geochronological evidence which has been obtained from the various subdivisions recognised within the Cordillera Real. However, in common with previous attempts, (see Litherland, 1987, for summary) our efforts to obtain what we believe represent original pluton and/or metamorphic ages have not been entirely successful. In particular a large number of K/Ar mineral determinations give consistently young ages when compared with the Rb/Sr and Sm/Nd dates and these are interpreted to reflect subsequent resetting (partial or otherwise) by later thermal events.

2.6.1 Sabanilla subdivision

Rb/Sr whole-rock 'errorchron' dates obtained from this subdivision suggest that an important thermal event occurred in the Cordillera Real between ca. 200-230 Ma (see 2.3.3d and Appendix 2b). However, the K/Ar mineral ages (Table 3) are invariably younger and, with the exception of obvious outlying points, give fairly consistent dates of between ca. 85-65 Ma (Fig 4). Contrary to what might be expected, it can also be seen from Table 3 that muscovite ages in the Sabanilla division tend to be younger than those obtained from biotite.

2.6.2 The Tres Lagunas and Agoyán subdivisions

At present the best estimate for the age of the Tres Lagunas subdivision is ca. 200 Ma (see 2.3.3.1 and Appendix 2b). Metamorphism of the Agoyán subdivision is assumed to be of a similar age. It should be noted that samples from the Papallacta area (Appendix 2b, sample 1A; Appendix 8, sample 4, in Litherland, 1989) gave hornblende ages of 324 ± 16.5 Ma and 367 ± 9.5 Ma and an average biotite age of 863 ± 32 Ma (Appendix 2b, sample 1B) which may hint at the presence of an older metamorphic basement in the area. In spite of these older dates much younger K/Ar mineral ages have also been obtained from both these subdivisions and they are listed in Table 4 and plotted in Fig. 5.

Examination of Table 4 reveals that in the case of the Tres Lagunas subdivision muscovite ages are consistently older than biotite ages from the same sample and this is especially clear in the case of the Malacatos samples (Muscovite) 98-99 Ma; (Biotite) 63-64 Ma. If one assumes that these three older ages are partially reset then the majority of the other disturbed ages fall between 55-85 Ma. This is similar to, but a somewhat more extended and younger range than, the 65-85 Ma shown by the Sabanilla subdivision.

2.6.3 Summary of the geochronological evidence and the interpretation of the Cretaceous to earliest Tertiary disturbed ages

With the exception of a few older dates, in particular those from the Papallacta area, the oldest recognisable metamorphic event in the Cordillera is of probable Late Triassic to possibly earliest Jurassic age. This event affected the rocks of the Loja division (Sabanilla and Tres Lagunas subdivisions) and it possibly correlates with similar ages which have been obtained from metamorphic and plutonic rocks in the El Oro Province (Table 2, in Litherland, 1987; Appendix 2b, this report). Between ca. 150-190 Ma major plutonism occurred in Ecuador which resulted in the emplacement of the Abitagua and (?)Azafrán subdivisions and the formation of their associated volcanic/volcano-sedimentary sequences (Misahuallí and ?Upano subdivisions).

As discussed in 2.6.1 and 2.6.2 numerous disturbed K/Ar mineral ages have been obtained from the Sabanilla, Tres Lagunas and Agoyán subdivisions. A few young ages have also been noted from the Abitagua and Zamora batholiths and the Azafrán subdivision (see 2.3.4.2, 2.3.5.1 and also Appendix 8, in Litherland, 1989). This information, together with the principal sedimentary/tectonic events, as evidenced by the Cretaceous to early Tertiary sedimentary record on the flanks of the Cordillera Real, has been plotted in Fig. 6. While it should be clearly understood that the interpretation of disturbed mineral ages is often difficult, especially when the effect of successive tectonic events is superimposed, several features apparent from Fig. 6 warrant further comment.

Following the cessation of plutonism in the Abitagua and the (?)Azafrán subdivision at ca. 150 Ma the Cordillera Real was subjected to major tectonism and it has been suggested elsewhere that this event was related to the collision of the Alao division along the line of the Baños front (Aspden et al., 1988). Evidence that significant transpressional shearing affected the Cordillera at or about this time comes from the Azafrán batholith. As mentioned earlier (2.3.4.2), concordant hornblende/biotite ages of 128 ± 7 Ma and 128 ± 4 Ma have been obtained from a deformed monzodiorite/diorite whereas older concordant, hornblende/biotite dates of 171 ± 5 Ma and 176 ± 5 Ma were obtained from an undeformed sample away from the shear zone. It was also suggested that the Azafrán batholith 120 ± 5 Ma isochron relates to this episode and, as can be seen in Fig. 6, several young Zamora and Abitagua batholith K/Ar ages, some of which are from discordant hornblende/biotite pairs, apparently can be attributed to this same event. Assuming a Jurassic age for the Upano subdivision then these rocks must have been metamorphosed to greenschist, and in part amphibolite, facies at this time. However, no firm evidence exists for the age of this subdivision and it is entirely possible that all, or part of the Upano could pre-date the Azafrán and Abitagua subdivisions as could its original age of metamorphism.

Table 3. Disturbed K-Ar mineral ages from the Sabanilla subdivision

Sample	Mineral	Age (Ma)	Area
FV-57	Bt	83 ± 2	East of Zamora, Loja road
FV-58	Bt	97 ± 3	
23-D	Bt	82 ± 3	
23-E	Bt	82 ± 3	
23-F	Bt	82 ± 3	
12-A	Musc	65.7 ± 2	
	Bt	84.5 ± 3	
12-C	Musc	65.6 ± 2	
	Bt	$72 \pm 2^*$	
	Bt	$81 \pm 2^*$	
	Bt	$52 \pm 2^{**}$	
24-A	Hb	131.5 ± 7	Valladolid area
	Bt	76 ± 3	
24-B	Musc	77 ± 3	
24-C	Musc	65 ± 2	
24-D	Bt	72 ± 2	
10-A	Musc	68.8 ± 2	
	Bt	84.7 ± 2	
10-C	Musc	73.4 ± 3	
	Bt	81.8 ± 2	
10-D	Bt	81.8 ± 2	

Datos sources: Appendix 4, in Litherland, 1987

Appendix 8, in Litherland, 1989

Appendix 2b, in this report

* Kennerley, 1980

** Baldock, 1982

Bt = Biotite

Mosc = Muscovite

Hb = Hornblende

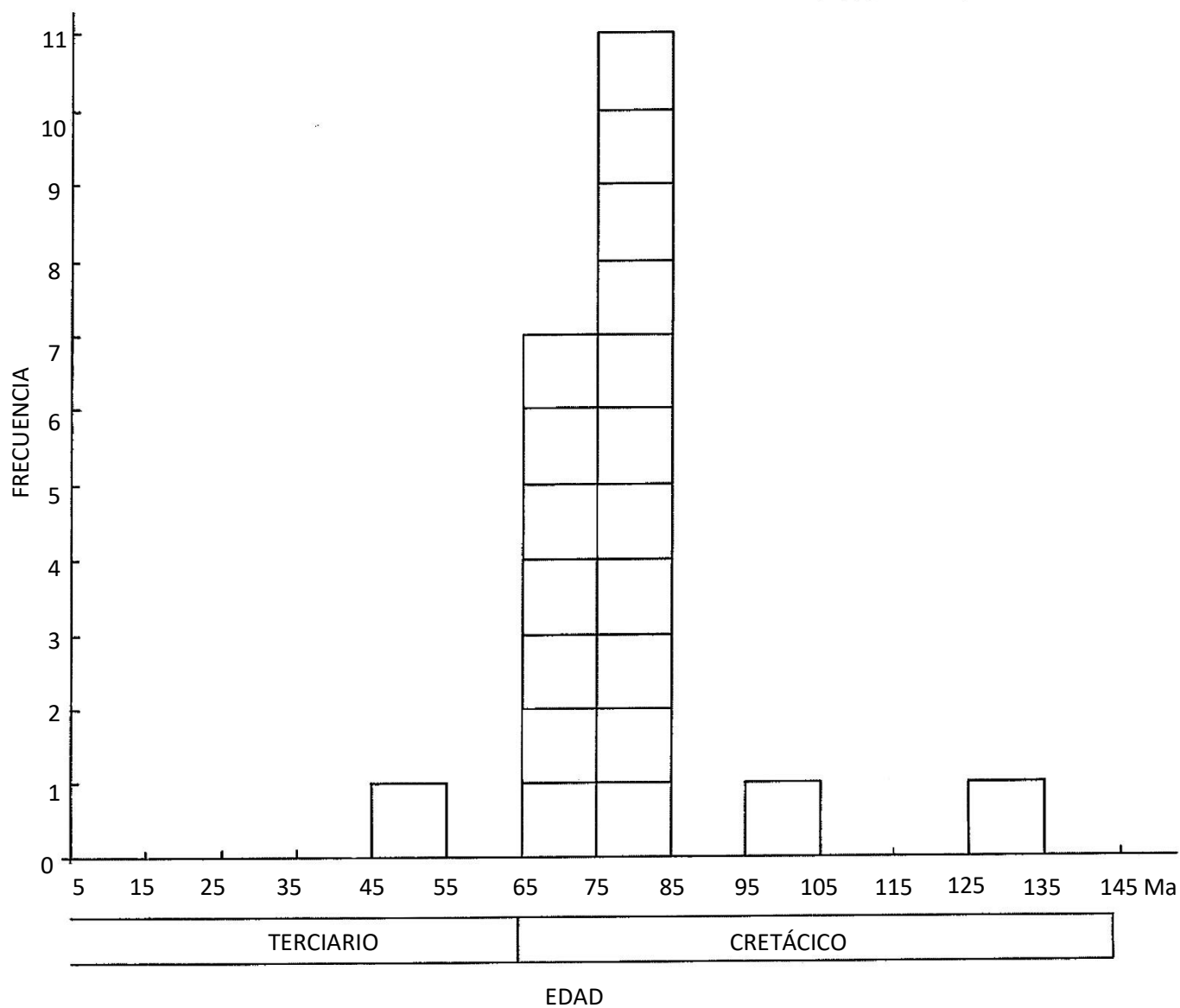


Figure 4. Disturbed K-Ar mineral ages from the Sabanilla subdivision

Table 4. Disturbed K-Ar mineral ages from the Tres Lagunas and Agoyán subdivision

Sample	Mineral	Age (Ma)	Area
Tres Lagunas subdivision			
11-A	Musc	99.6 ± 3	Malacatos
	Bt	64.6 ± 9	
11-B	Musc	98.5 ± 3	
	Bt	63.1 ± 3	
11-C	Musc	98.9 ± 3	
	Bt	65.5 ± 2	
14-D	Bt	61.7 ± 2	Tres Lagunas area east of Saraguro
	Musc	67.5 ± 3	
14-E	Bt	50.5 ± 2	
	Musc	73.1 ± 2	
14-F	Bt	61.7 ± 2	
	Musc	68.8 ± 2	
14-A	Bt	81 ± 3	Peggy Mine area
14-D	Bt	86 ± 4	
Agoyán subdivision			
11-B	Mica	78 ± 33	Baños-Puyo
11-D	Mica	74 ± 27	
11-E	Mica	75 ± 7	
	Musc	56.5 ±2 *	
	Musc	60 ± 2 *	
1-C	Musc	73.7 ± 3	

Datos sources: See Table 3, in this report

* Herbert and Pichler (1983)

Bt = Biotite
Mosc = Muscovite

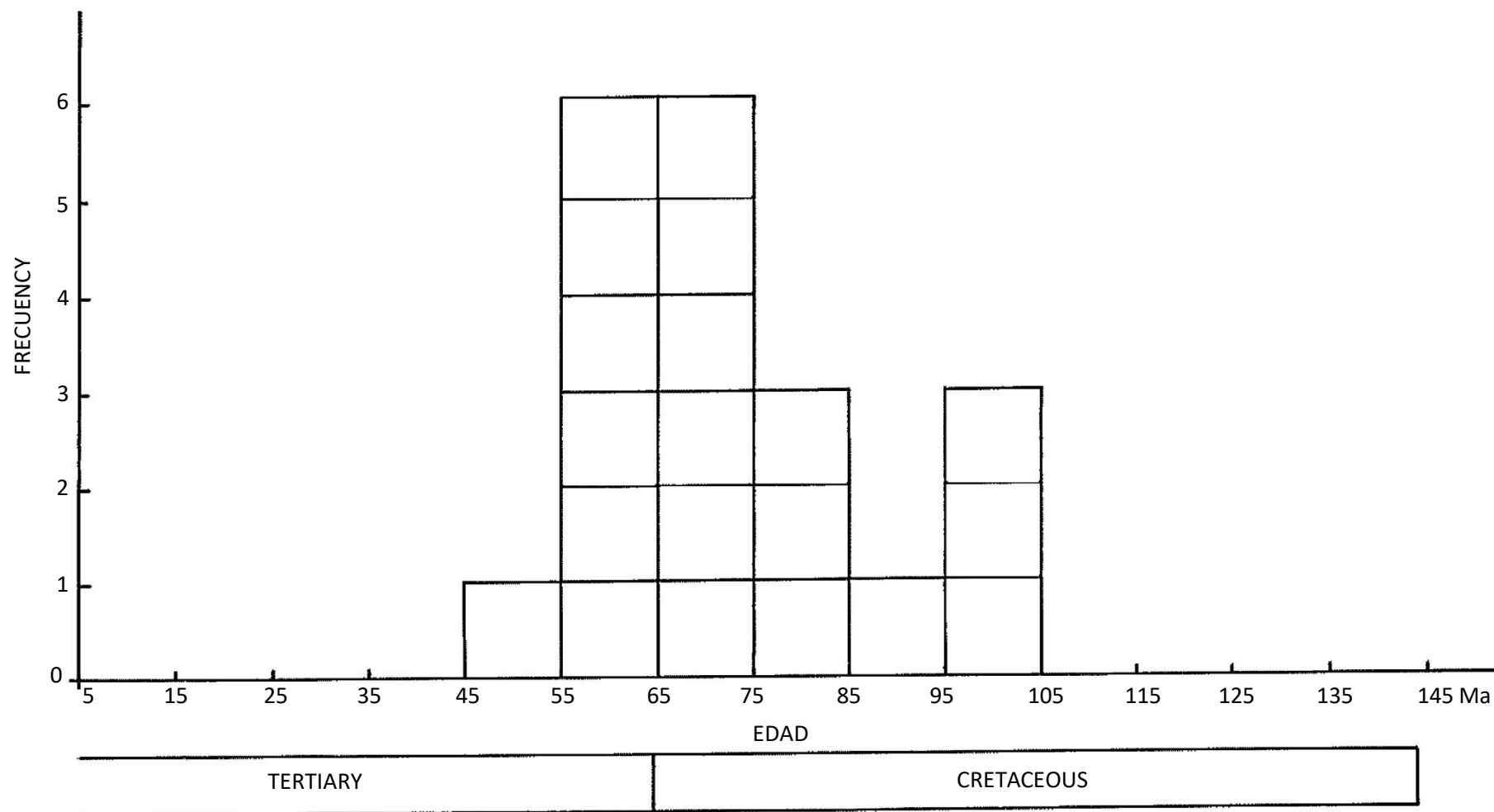
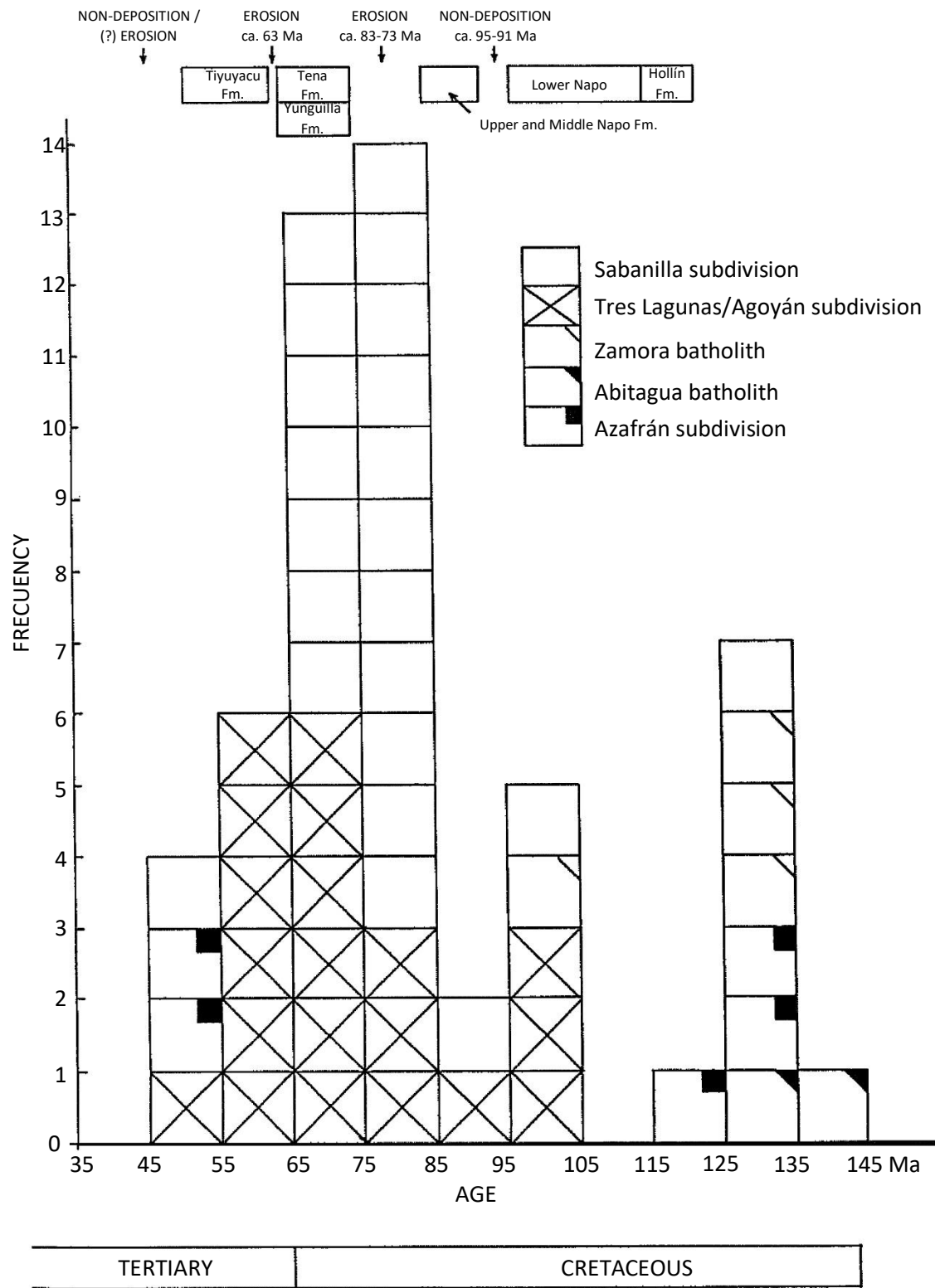


Figure 5. Disturbed K-Ar mineral ages from the Tres Lagunas and Agoyán subdivision



Data sources: Table 2

Figure 6. Disturbed/reset radiometric ages from the Cordillera Real (Cretaceous to earliest Tertiary)

Following the collision of the Alao division extensive erosion took place in the sub-Andean zone prior to the deposition of the Hollín Fm. from the west. The base of the Hollín Fm. is poorly dated but it is generally considered to be Aptian (ca. 119-113 Ma), (Bristow and Hoffstetter, 1977) and although interstratified lavas and tuffs are present in the Lower Napo (Baldock, 1982) these formations were laid down under relatively stable conditions on the edge of an extensive epicontinental shelf.

The Middle and Lower Napo are separated by a period of middle to upper Cenomanian non-deposition (ca. 95-91 Ma) which may correlate with a small peak of disturbed mineral ages in Fig. 6 of 95-105 Ma. Following the deposition of the Upper Napo Fm. an important period of Campanian erosion (ca. 83-73 Ma) (Baldock, 1982) took place and this, together with the subsequent deposition of the Tena and Yunguilla Fms., coincides with the marked peak in disturbed mineral ages from the Cordillera Real. Sedimentological evidence from the Tena Fm. indicates that it was derived from the west (Baldock, 1982) and since the Yunguilla Fm. is confined to the western flanks of the Cordillera then it seems reasonable to conclude that the widespread Late Cretaceous thermal resetting may be related to the emergence of the Cordillera Real as a positive topographic feature (see also Baldock, 1982).

Evidence from the sedimentary record clearly indicates that conditions of instability continued throughout much of the Lower Tertiary. In the Oriente, Middle Eocene to Upper Oligocene sediments are absent and an erosional unconformity separates the Tena Fm. from the overlying Tiuyacu 'red bed' succession with its coarse basal conglomerate (Baldock, 1982). In the west, for example in the Cuenca basin, the Yunguilla Fm. is overlain directly by Miocene sediments (Bristow and Guevara, 1980) and it appears from Fig. 6 that these events are also reflected in continued thermal overprinting of the metamorphic rocks in the Cordillera Real.

In regional terms the 85-55 Ma event (Late Cretaceous to Palaeocene) is interpreted to correspond, at least in part, with the approach and subsequent accretion of the Western Cordillera along the Calacalí-Pallatanga-Palenque fault (Aspden et al., 1987, 1988). During this time plutonic activity within the Cordillera was restricted (2.4.2 and 2.4.4) and it is suggested that the necessary thermal energy to account for such a widespread resetting must have been generated during the uplift of the Cordillera Real, principally as a result of either frictional heating along shear zones and/or by crustal thickening.

3. MINERAL OCCURRENCES AND GEOCHEMICAL ANOMALIES

As in previous Annual Reports the mineral groupings used in this chapter follow those of the Mining Journal. Only mineral occurrences and geochemical anomalies found during the past 12-month period are noted here. In Map 9 economic information to the south of, and including, the Río Paute has been included in earlier Annual Reports. Equally only the new mineral occurrences, for the Atillo-Macas (Río Abanico) traverse are dealt with, previous information can be found in Litherland (1987).

All the currently available geochemical analyses of stream sediments and rock samples, together with their locations, are given in Appendix 6. Appendix 6a lists those analyses carried out in the INEMIN laboratories and includes both stream sediment and rock analyses. Appendix 6b includes only rock analyses which were carried out either by ACME Laboratories, Vancouver, Canada or by Caleb-Brett, St. Helens, UK.

The reader is also referred to Appendix 7a which details minerals of economic interest that have been identified in panned concentrates collected from the Cordillera Real over the past four years. The locations of these samples are given in Maps 10 and 11 and semi-quantitative XRF analyses of some of the panned concentrates are included in Appendix 7b. At the time of writing Appendix 7 is in preparation and therefore will not be discussed further in this report. In addition, Appendix 4b describes a series of thematic rock suites, some of which are of known economic interest.

3.1 Precious metals

3.1.1 Gold and silver

3.1.1.1 Alluvial occurrences (Au): Gold has been panned, or seen to be worked, in a number of rivers and these locations are indicated on the 1:250000 geological maps (Maps 8 and 9). Additional occurrences of gold are also shown on the two traverse maps which cover part of the southern Cordillera Real (Maps 3 and 4). In the following areas/rivers gold is worked commercially by small-scale operators/cooperatives:

- (a) Ortega Alto - when visited by the project some 17 miners were working this (?) colluvial deposit. The source of gold in this historic site is not known but the area has been studied by INEMIN (1986) (see also Appendix 1e, Map 3).
- (b) Río Tutupali - worked extensively, usually by small family groups. A projected commercial dredging operation to the north of La Paz was paralysed when the area was last visited, due to disputes over land tenure (Maps 3 and 4).

- (c) Río Palora - mainly downstream of, but including, the Río Coco and Río Sangay. This operation includes various groups but probably involves in excess of 100 people, largely working inside the Parque Nacional de Sangay. Promising gold showings (6 coarse flakes in 2 pans) were also panned from the Río Benado, a north bank tributary of the Río Palora, located ca. 1.5 km upstream of the Río Coco (Maps 6 and 9).
- (d) Río Illushín - mainly worked between 1-3 km upstream from its junction with the Río Pastaza (Map 9) during the drier months of the year. Up to 20 miners are involved in this operation.
- (e) Río Cofanes - in the area of Puerto Libre (Aguarico) alluvial gold is worked by some thirty family groups and also by the Arajuno Mining Company. According to information received by the project, alluvial gold was discovered below La Sofía in 1979 and nuggets of up to 30 grams have been recovered from this area (see Appendix 1c and Map 2).
- (f) Río Minas - although the Río Minas is apparently not being worked for gold, promising shows of 12 flakes of gold/pan were obtained. Some of the gold flakes were up to 1 mm across (Appendix 1b and Map 1).

3.1.1.2 Geochemical anomalies (Au and Ag): Au and Ag analyses of rock samples submitted to Caleb Brett and ACME Laboratories (Appendix 6b) generally gave low values of between 0.4-39 ppb (Au) and <1 ppm (Ag). Somewhat higher values of 491 ppb (Au) and 2.8 ppm (Ag) were obtained from a mineralised float sample (CR-HL-667) from the Río Quijos (Papallacta-Baeza road) and 5 ppm (Ag) and 2 ppm (Ag) were recorded from CR-FV-908 and M-667C. CR-FV-908 is a cross-cutting quartz-sulphide vein from the NW of Alao (Map 6) and M-667C is a metavolcanic block from Quebrada Las Juntas, a west bank tributary of the Río Chingual (Map 2).

Consistently higher Ag values were obtained from the INEMIN laboratories (Appendix 6a).

- (a) Rock samples 553-K and 553-L1, from the Sara Urco area (Map 6, in Litherland, 1989) gave 10 and 13 ppm Ag respectively and in 553-L1 0.2 ppm Au was detected.
- (b) A block of pyritic Napo Fm. from the Río Cascabel (607B) and a pyritised porphyry from the Río Salado (609B) yielded Ag values of 6 and 8 ppm (Map 7, in Litherland, 1989).

- (c) A254F and A257F stream sediment samples from the Río Tambo Blanco and Río Cristal (Jimbilla-Río Quimi traverse, Map 3) gave values of 7 ppm and 3 ppm Ag respectively.
- (d) Fluvial samples A263F (Río Cambana), A272F (Río Espadillas), A275F (Quebrada El Guando Chico) and A277F (Río Salado) from the Tutupali-San José de Yacuambí area gave Ag values of between 4-6 ppm (Map 4).
- (e) Duplicate samples A279A-K collected from the Río Chica (Map 4) gave Ag values which varied from 1 ppm to 12 ppm.

3.2 Older major metals

3.2.1 Copper

- (a) In the Río Cambana chalcopyrite was noted near to the contact of the Zamora batholith and a stream sediment sample from this river (A263F) contained 90 ppm Cu. (Appendix 1e, Map 4 and Appendix 6a).
- (b) Chalcopyrite and bornite were identified in float blocks of volcanics from the Río Campana Urco (Appendix 1e, Map 4). A stream sediment sample (A271F) from downstream of the junction in the Río Espadillas however yielded only 39 ppm Cu (Appendix 6a).
- (c) 63 ppm was recorded from a sediment sample from the Río Salado, a south bank tributary of the Río Cantzama, to the west of Guadalupe (Map 4, Appendix 6a, A277F).
- (d) Relatively high Cu values (54-106 ppm) were obtained from stream sediment samples from the Río Tutanangoza to Río Ojal traverse (Appendix 6a, CR-RB-191-195).
- (e) Chalcopyrite, together with other sulphides (mainly pyrite), is associated with small felsic dykes and sheets along the western margin of the Salado pluton (Map 9).
- (f) N-S sulphide-bearing shear zones to the east of Peltetec in the Alao Valley, in the Alao-Paute subdivision, carry traces of chalcopyrite. It is also present within small quartz-sulphide veins in the Tres Lagunas subdivision further to the east (Appendix 1f, Maps 5 and 9).

- (g) The following Cu values were obtained from stream sediments in the La Sofia-Río Cofanes-Puerto Libre area (Map 2, Appendix 6a): 68 ppm (CR-ML-143F, Río San Jorge); 68 ppm (CR-ML-146F, Q. La Industria); 76 ppm (CR-ML-147F, Q. Las Juntas) and 68 ppm (CR-ML-148F, Q. El Bicundo).

Rock samples from the same area (Appendix 6b) gave: 269 ppm (M-659F, float block, Río Cofanes); 692 ppm (M-667C, float block, Q. La Industria) and 1303 ppm (M-668 float block, Q. Las Juntas).

In addition to these occurrences concordant quartz veins which carry minor chalcopyrite are present in mylonite granodiorite to the south of La Sofia in the Río Cofanes. To the north of La Bonita chalcopyrite was noted along the new road where it is associated with the contact zone of a small Tertiary porphyry (Appendix 1c, Map 2 and Map 8).

- (h) A float sample of muscovite gneiss from the Río Condué (CR-MC-653A, Appendix 6b) contained 1510 ppm Cu.
- (i) Rock samples from the Sara Urco area (Map 6, in Litherland, 1989) gave the following Cu values: 553L.1 773 ppm; MP-553D.1 357 ppm; CR-MP-553D.2 234 ppm; MP-554C 85 ppm; MP554F 146 ppm.
- (j) A sample of metabasalt outcrop from the Río Blanco de Patate contained 150 ppm (Appendix 1a).
- (k) An outcrop of mineralised porphyry in the Río Salado contained 109 ppm Cu (MP-609 and MP-609B) (Map 7, in Litherland, 1989).
- (l) Mineralised float from the Río Quijos (Papallacta-Baeza road) gave Cu values of 120 ppm (CR-HL-677, Appendix 6b).
- (m) Minor amounts of chalcopyrite were noted in the area around Monte Olivo (Appendix 1b, Map 1 and Map 9).

3.2.2 Lead and zinc

- (a) Pb and Zn analyses obtained from sediment samples (Appendix 6a) range up to 166 ppm and 147 ppm respectively. Duplicate samples from the Río Chicana gave values of Pb between 132-166 ppm and Zn 74-100 ppm. Samples A263F (R. Cambana) gave 157 ppm Pb and 76 ppm Zn; A271F (R. Campana Urco) gave 107 ppm Pb and 145 ppm Zn; A272F (R. Espadillas) gave 107 ppm Pb and 147 ppm Zn and A277F (R. Salado) gave 132 ppm Pb and 136 ppm Zn (see Map 4).

“Anomalous” Pb values were also recorded from the following samples: A257F (R. Cristal, Map 3) 101 ppm; A262F (R. Quimi, Map 4) 107 ppm; CR-ML-141F (Río Cofanes, Map 2) 96 ppm.

- (b) A silicified/epidotised volcanic block from the Río Cantzama (Map 4, CR-FV-770) contained 633 ppm Zn.
- (c) Mineralised rock samples from the Sara Urco area (553K, 553L.1, Map 6, in Litherland, 1989) carry up to 1133 ppm Zn and 238 ppm Pb (Appendix 6a).
- (d) 7593 ppm Zn was recorded from a float in Río Quijos (CR-HL-677) (Papallacta-Baeza road).
- (e) Rock samples from the Ríos Salado and Cascabel (MP-609; MP-609B and MP-607, Map 7 in Litherland, 1989) contained up to 515 ppm Zn and 121 ppm Pb.
- (f) Quartz sulphide veins within the Tres Lagunas subdivision to the east of the Río Alao contain up to 3170 ppm Pb and 42 ppm Zn (CR-FV-908, Maps 6 and 9).
- (g) In the Monte Olivo/San Gabriel area (Map 1) the following 'anomalous' Zn values were obtained: CR-MC-640B (near El Carmen) 173 ppm; CR-MC-642B (R. Minas) 248 ppm; CR-MC-644G (Q. Juan Ibarra) 288 ppm; CR-MC-645B (Ambuquí area) 236 ppm and CR-RB-180A (R. Blanco) 100 ppm.
- (h) In the Río Condué float blocks (652B and 653A, Map 1) gave Zn values of 478 ppm and 332 ppm respectively.
- (i) In the La Sofía-La Bonita area (Map 3) the following Zn values were obtained from mineralised samples: M659F (R. Cofanes) 139 ppm; M-667C (Q. La Industria) 38,743 ppm; M-667D (Q. La Industria) 244 ppm and M-668 (Q. Las Juntas) 1211 ppm.
- (j) A sample of ?Napo Fm. limestone (RB-159A) from the R. Mulatos (Map 7, in Litherland, 1988) yielded 110 ppm Zn.
- (k) Minor amounts of Pb (134 ppm) were present in an altered/kaolinised sample of Tres Lagunas granite (A169, Map 3).
- (l) Values of up to 154 ppm Zn and 93 ppm Pb were obtained from rock samples from the Río Blanco de Patate and Río Verde (Appendix 1a).
- (m) A loose block of garnet-bearing granite from the Oyacachi area (CR-MP-462B/C, Map 3, in Litherland, 1989) contained 100 ppm Zn.

3.2.3 Tin

Small concentrations of tin ranging from 11 to 33 ppm are present in float samples of pegmatites collected from Q. Juan Ibarra to the east of San Gabriel (Map 1) (CR-MC-642B 643B and 644G, Appendix 6b).

3.3 Steel industry metals

3.3.1 Chromium

Three float samples of serpentinite contained the following Cr values: M-659A (R. Cofanes) 2216 ppm; M-659B (R. Cofanes) 670 ppm and M-677 (R. Huagracyacu) 971 ppm. A small outcrop of a carbonated serpentinite vein (10 cm across) near to Monte Olivo (CR-MC-640B) yielded 1410 ppm Cr. Levels of 1-3000 ppm Cr are standard for ophiolitic complexes worldwide (Hutchinson, 1983).

3.3.2 Cobalt

The highest Co recorded was 112 ppm for a block of skarn from the Río Verde (M-637). Elsewhere values are less than 100 ppm. Three samples from Sara Urco (533-K, 533L.1 and CR-MP-553D.2) gave analyses of 59-97 ppm Co and M-667C contained 79 ppm Co. Other values between 54-79 ppm were obtained from serpentinite float blocks (M-659A, M659B and M677).

3.3.3 Iron and manganese

- (a) Magnetite is present in the Río Verde skarnfield (Appendix 1a) and in the Sara Urco area (Map 6, in Litherland, 1989).
- (b) Small (up to 1 cm) ?tectonic lenses of magnetite were noted in quartz-feldspathic float in the Río Minas (Appendix 1b).
- (c) In the Río Condué small magnetite disseminations occur in a pegmatitic facies of the Condué granite.
- (d) Magnetite is present both as small veinlets and as somewhat more massive blocks in the Río Campana Urco and Río Espadillas (Appendix 1e).
- (e) Fe and Mn analyses are listed in Appendix 6.

3.3.4 Molybdenum

A maximum Mo value of 556 ppm was recorded for MP-554C from the Sara Urco area. Other analyses samples contained <30 ppm Mo.

Minor amounts of molybdenite were noted in float blocks in the Río San Miguel to the East of Monte Olivo and also in thin quartz stringers along the eastern margin of the Chingual pluton (Map 8).

3.3.5 Nickel

The highest value of 1736 ppm Ni comes from the Sara Urco area (553L.1). Between 665-1613 ppm Ni was detected in various serpentinites from the Cordillera Real (M-677, M-659A, M-659B and CR-MC-640B) and a sample of nickeliferous pyrite from the Napo Fm. (609B) contained 610 ppm Ni. None of these latter occurrences are considered to be of economic interest.

3.3.6 Tungsten

Although scheelite is relatively common in panned concentrates from the Cordillera Real (Appendix 7) no 'anomalous' W values are present in Appendix 6.

3.3.7 Titanium

Brownish red rutile crystals up to 4 cm in length are present in medium grained gneisses to the east of Monte Olivo (Map 8). This occurrence is probably of mineralogical curiosity only.

3.3.8 Vanadium

Several stream sediments samples from the San José de Yacuambí area have V values >100 ppm. The highest concentration of 189 ppm was obtained from R. Cambana (A263F, Appendix 6a, Map 4). Rock samples (CR-FV-757A and CR-FV-770) also from the same area contained 242 and 300 ppm V respectively.

The following samples from elsewhere in the Cordillera Real, CR-MP-462B/C, CR-MC-642B and MP-554C contained between 103-244 ppm V.

3.4 Fuel minerals

3.4.1 Oil

In Río La Chispa and in two other unnamed west bank tributaries of the Río Chingual float of bituminous shales, of probable Napo Fm., were noted (Map 2).

3.5 Electrical metals and minerals

3.5.1 Cadmium

M-667C and CR-ML-677 contained 494 ppm and 110 ppm Cd respectively. A lower value of 17 ppm Cd was recorded in sample M.668.

3.6 Chemical metals and minerals

3.6.1 Antimony

M-667C gave 22 ppm Sb and 11 and 10 ppm were recorded from M-659A and M-659B.

3.6.2 Barium

M-662 contained 441 ppm Ba.

3.6.3 Bismuth

A maximum value of 3 ppm Bi was found in CR-MP-553D.2.

3.6.4 Kaolin

In the area of Rosa Florida pluton kaolin-rich clays are present (Map 8). Zones of kaolinisation were also noted within the Tres Lagunas batholith near its eastern margin in the southern part of the Cordillera (Map 3).

3.6.5 Sulphur

Minor amounts of native sulphur, associated with zones of pyritic alteration, are present within the Tarqui Fm. near to Atillo, along the track which leads to Laguna Atillo (Map 9).

3.7 Nuclear and radioactive metals

3.7.1 Uranium

A small 30 cm band of uraniferous phosphate outcrops in the Río Chingual to the north of Puerto Libre (Map 8) (Vera, 1980).

3.7.2 Thorium

A value of 38 ppm Th was recorded from CR-FV-908 and 27 ppm and 30 ppm from CR-MP-462B/C and MP-554F.

3.8 Insulants and refractors

3.8.1 Asbestos

Minor amounts of asbestiform amphibole are present on shear surfaces in mafic greenstones in the Río Palmar but are of no commercial value (Appendix 1b, Map 2).

3.8.2 Graphite

Graphitic phyllites are present to the east of Jimbilla (Map 3) and indeed are relatively common throughout the Chigüinda subdivision (see previous Annual Reports). These occurrences are unlikely to be of economic interest.

3.9 Other industrial minerals rocks and gemstones

3.9.1 Carbonate

Apart from limestones within the Napo Fm. (Tschopp, 1953; Baldock, 1982) massive blocks of marble and travertine exist in the Río Cofanes (Appendix 1b, Map 2).

3.9.2 Garnet

Garnet is a relatively common mineral in the Cordillera Real where it is sometimes referred to as “ruby”. The occurrences are of probable mineralogical, rather than economic, interest.

- (a) Garnet is most widespread in the various skarnfields to the north of the Pastaza river where it can form 20 cm thick bands of high pyrite (Litherland et al., 1990).
- (b) Euhedral garnets (2-3 cm across) are present in float blocks in the Río Collanes, a north bank tributary of the Río Palora (Map 6).
- (c) 5 mm red garnet of high purity which were seen in Puerto Libre, had reportedly been collected from Q. Culebrillas near to La Bonita (Appendix 1c, Map 2).

3.9.3 Ornamental stone

Attractive pale red and grey monzonite and syenite blocks occur in Río La Chispa a west bank tributary of Río Chingual (Map 2).

3.9.4 Phosphate

Vera (1930) reported the presence of uraniferous phosphate within the Napo Fm. in the Río Chingual (Map 2). This band is 30 cm thick and is of little economic interest. A regional synthesis of phosphates in the Napo Fm. is given by Boujo et al. (1984) and Wilkinson (1982).

3.9.5 Silica

Pure Hollín Fm. quartzites outcrop along the right-hand bank of the Río Chuchumbleza (Appendix 1e, Map 4).

3.9.6 Tourmaline

Black tourmaline is relatively common in the Cordillera where it is frequently associated with the Tres Lagunas subdivision.

- (a) Small crystals of tourmaline (generally <1 cm) are present towards the eastern margin of the Tres Lagunas batholith where they are associated with zones of kaolinisation (Map 3, Oñacapa-Yacuambí traverse).
- (b) 2-3 cm tourmaline crystals occur in float blocks of granitic gneiss in the Río Cristal, a south bank tributary of the Río Palora (Maps 6 and 9).
- (c) To the east of San Gabriel in the area of Río Minas and to the east of Monte Olivo (Maps 1 and 8) tourmaline crystals up to 3 cm in length are associated with the belt of pegmatitic Tres Lagunas subdivision.

4. REFERENCES

- ALY S. (1980)** Petrologische Untersuchungen plutonischer Gesteine von Ecuador. PhD Thesis, Univ. Tübingen, (Unpubl).
- ASPDEN J. A., McCOURT W. J. and BROOK M. (1987)** Geometrical control of subduction-related magmatism: the Mesozoic and Cenozoic plutonic history of Western Colombia. *J. Geol. Soc. Lond.*, Vol. 144, pp. 893-905.
- ASPDEN J. A., LITHERLAND M., DUQUE P., SALAZAR E., BERMÚDEZ R y VITERI F. (En prensa)** Un nuevo cinturón ofiolítico en la Cordillera Real, Ecuador, y su posible significado regional. *Politécnica*, Vol. XI, No. 2, pp. 81-93, Quito.
- ASPDEN J. A., LITHERLAND M. y SALAZAR E. (1988)** Historia colisional del centro y sur del Ecuador y posibles controles para la geología cenozoica y de mineralización polimetálica. *Politécnica*, Vol. XIII, No. 3, pp. 49-75, Quito.
- BALDOCK J. W. (1982)** Geología del Ecuador. Boletín de la explicación del Mapa geológico de la República del Ecuador 1:1.000.000. Dir. Gen. Geol. y Minas. Quito.
- BERTHÉ D., CHOUKROUNE P. and JEGOUZO P. (1979)** Orthogneiss, mylonite and non-coaxial deformation of granites, the example of the South Armorican Shear Zone. *J. Struct. Geol.*, Vol. 4, pp. 31-42.
- BOUJO A. et al. (1984)** Proyecto Fosfatos. Dir. Gen. Geol. y Minas, Quito (no publicado).
- BRISTOW C. R. (1973)** Guide to the geology of the Cuenca basin, Southern Ecuador. Quito: Ecuadorian Geological and Geophysical Society.
- BRISTOW C. R., LONGO R. y GUEVARA S. (1975)** Mapa geológico de Cañar (Hoja 72) (1:100000). Dir. Gen. Geol. y Minas, Quito.
- BRISTOW C. R. and HOFFSTETTER R. (1977)** Lexique stratigraphique International (2nd Ed.) (Paris: Centre National de la Recherche Scientifique).
- BRISTOW C. R. y GUEVARA, S. (1980)** Mapa geológico de Azogues (Hoja 73) (1:100000). Dir. Gen. Geol. y Minas, Quito.
- BUTLER R. W. H. (1983)** The terminology of structures in thrust belts. *J. Struct. Geol.*, Vol. 4, pp. 239-245.
- CHAPPELL B. W. and WHITE A. J. R. (1974)** Two contrasting granite types. *Pacific Geology*, Vol. 8, pp. 239-245.
- EVERNDEN J. (1961)** Edades absolutas de algunas rocas ígneas en Bolivia. *Noticiero Soc. Geol. Boliviana*, 2-3; La Paz.
- FEININGER T. (1975)** Origin of petroleum in the Oriente of Ecuador. *Bull. Am. Assoc. Pet. Geol.*, Vol 59, pp. 1166-1175.
- FEININGER T. (1982)** The metamorphic "basement" of Ecuador. *Geol. Soc. Amer. Bull.*, Vol. 93, 87-92.
- HALL M. and CALLE J. (1982)** Geochronological control for the main tectonic-magmatic events of Ecuador. *Earth Sci. Rev.*, Vol 18, 215-239.

HERBERT H. J. (1977) Die Grünschiefer der Öst-Kordillere Ecuador und ihr metamorpher Rahmen. PhD Thesis, Univ. Tübingen, Eberhard-Karls-Universität, (Unpubl).

HERBERT H. J. and PICHLER H. (1983) K-Ar ages of rocks from the eastern Cordillera of Ecuador. Z. dt. geol. Ges. Vol. 134, 483-493.

HUTCHISON C. S. (1983) Economic deposits and their tectonic setting. MacMillan, London.

INEMIN (1986) Informe de prospección del coluvial aurífero de Ortega Alto, Yacuambí-Zamora Chinchipe. INEMIN, Quito octubre 1986 (No publicado).

KENNERLEY, J.B. (1980) Outline of the geology of Ecuador. Overseas Geol. And Miner. Res. Inst. Geol. Sci. UK., No 55, 17 pp.

LASCANO F., MARÍN M. y VERSET Y. (1980) Mapa geológico de Macas (Hoja 90) (1:100000) INEMIN, Quito.

LISTER G. S. and SNOKE A. W. (1984) S-C Mylonites J. Struct. Geol., Vol. 6, pp. 617-638.

LITHERLAND M. (1987) Cordillera Real Geological Research Project: First Annual Report, INEMIN-Misión Británica, Quito (Unpubl).

LITHERLAND M. (1988) Cordillera Real Geological Research Project: Second Annual Report, INEMIN-Misión Británica, Quito (Unpubl).

LITHERLAND M. (1989) Cordillera Real Geological Research Project: Third Annual Report, INEMIN-Misión Británica, Quito (Unpubl).

LITHERLAND M., ASPDEN J. A., BERMÚDEZ R., VITERI F. and POZO M. (1990) Cordillera Real Geological Research Project: Summary Report 1986-1990, INEMIN-Misión Británica, Quito (Unpubl).

MORTIMER, C., MALO, G. y SALAZAR E. (1980) Mapa geológico de Baños (Hoja 88) (1:100000). Dir. Gen. Geol. y Minas, Quito.

SOSA H. y LONGO R. A. (1975) Mapa geológico de Alausí (Hoja 71) (1:100000). Dir. Gen. Geol. y Minas, Quito.

ROBERTS T. R. (1975) Characoid fish teeth from Miocene deposits in the Cuenca Basin, Ecuador. J. Zool. Lond., Vol. 175, pp. 265-271.

TSCHOPP, H.J. (1953) Oil exploration in the Oriente of Ecuador. Bull. Am. Ass. Petrol. Geol., Vol. 37, No 10, pp. 2303-2347.

VERA R. (1980) La fosforita uranífera, Río Chingual, Chingual, Provincia de Napo. Politécnica, Vol. 2, pp. 47-55, Quito.

WILKINSON, A. F. (1982) Exploration for phosphate in Ecuador. Trans. Inst. Min. Metal., B, Vol. 91, pp. 130-145.

APPENDIX 1

Field commission reports for the Cordillera Real from north to south
(1a – 1g)

INDEX

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No. 8216

QUITO, SEPTEMBER 14, 1989

TO : GERENTE TÉCNICO

FROM : DR. MARTIN LITHERLAND – CORDILLERA REAL PROJECT

SUBJECT : Technical Report of the commission carried out in the Cordillera Real, in the areas of the Yanayacu, Patate, Pastaza, and Quijos rivers, from August 30 to September 06, 1989.

1. INTRODUCTION

1.1 Project context

The geological technical collaboration project between the governments of Ecuador and Great Britain involves the collection of field data to understand the geology of the Cordillera Real, aimed at establishing a model of its formation processes; as well as its relationship with the environments that govern a possible mineral potential, for future local work concerning the Instituto Ecuatoriano de Minería.

1.2. Objectives

The commission that is the subject of this report was carried out from August 30 to September 06. This commission was planned to investigate new sites of geological-mining interest and re-examine areas studied by the Project in 1986, in order to use the data obtained to make a comparison with other sectors of the Cordillera Real.

1.3. Assigned personnel

To carry out this work, the commission was led by Dr. Martin Litherland, accompanied by Mr. Manuel Céleri as field assistant and driver.

1.4 Means of transport

Jeep Land Rover, license plate AT – 0274, from the British Mission.

1.5. Detailed activities

The collection of geological information was carried out according to the following breakdown of activities:

Month	Day	Traverse
August	30	Quito – San José de Poaló area (Río Yanayacu) – Baños
	31	Baños – Agoyán – Río Blanco (Río Pastaza).
September	01	Río Blanco – Río Topo (Río Pastaza).
	02	Río Blanco de Patate.
	03	Río Verde de Pastaza.
	04	Baños – Río Papallacta – Río Quijos – Baeza.
	05	Baeza – Río Quijos – Reventador – El Chaco
	06	El Chaco – Quito.

2. GEOLOGY

2.1 Introduction

The geological data obtained are described under the appropriate lithotectonic division, following the Third Annual Report of the Cordillera Real Project (Litherland, 1989).

2.2 Guamote division

On the western side of the Río Yanayacu (7847-78807) in front of the Pisayambo hydroelectric plant, near the town of San José de Poaló, there is an outcropping of orthoquartzites from the metamorphic basement. This large outcrop forms a cliff beneath the Tertiary volcanics and extends approximately 200 m from the river towards the northwest; it does not appear on previous maps (Kennerley, 1971; Guzmán, 1986). The outcrops comprise fine- to medium-grained orthoquartzite of pink, light grey, dark grey, and black colours. There are also quartz schists and pale phyllite bands; sedimentary microbreccias of black shale clasts.

Due to the lithologies and geographic position, the rocks of this outcrop are correlated with the Guamote Division which outcrops near Punín and further south.

2.3 Peltetec and Maguazo divisions

In the same area of San José de Poaló, along a road 800 m south and southeast of the Guamote Division outcrop, there is an outcrop noted by Kennerley (1971) of green phyllites, acidic metatuffs, black phyllites, and banded fine quartzose turbidites. This lithological sequence belongs to the Maguazo Division.

In the Río Blanco de Patate (La Joya Sheet) upstream from a point (7806-98588) east of Poaló, there are outcrops of metabasalts and ultramafic rocks, metatuffs, and purple and black phyllites, fine turbidites, and dark calcareous sandstones. This sequence comprises the Peltetec Division, followed to the east by rocks of the Maguazo Division.



Thus, two new outcrops of the Peltetec (ophiolitic) and Maguazo (fore-arc) divisions are located further north than those previously known, Alao-Penipe (Litherland, 1988).

2.4 Tres Lagunas division

To the east of the Baños front, in most of the Cordillera Real, outcrops of the Tres Lagunas granite occur; however, this lithology was not observed on the road east of Baños (Litherland, 1987).

Along the road between the bridge over the Río Pastaza, near the Agoyán Dam, to the Agoyán Waterfall, there are no outcrops for a distance of one and a half kilometres. In this commission, we followed the path south of the Río Pastaza where mostly metagranitic orthogneiss outcrops, in some places with the appearance of Tres Lagunas type granite (blue quartz). The orthogneiss changes its appearance from mylonitic and foliated to without major deformation throughout the traverse. There are amphibolitic dikes that penetrate the granite, which can be better observed in the large boulders in the dry Río Pastaza. The dikes have foliated margins parallel to the tectonic fabric in the orthogneiss, indicating a syn- or pre-tectonic age. There are also paragneiss xenoliths. There is a pegmatitic concentration of quartz and hornblende at the contact of the dikes. It is assumed that the dike crossing the Agoyán Waterfall is of this class.

The other lithologies of the “Tres Lagunas” division include paragneisses and schists with garnet and muscovite ($\pm$ chloritoid) and garnetiferous metapsammities.

2.5 Azafrán division

Following the Project studies, the Azafrán plutonic phase extends through most of the northern Cordillera Real. The type section at the Azafrán quarry indicates a quartz monzonite ranging from an undeformed state to mylonitic. Between the Blanco River and the Río Verde, the present revision indicates most of it as a metadioritic phase tectonically intercalated with muscovite, garnet, and chloritoid schist.

2.6 The Llanganates skarn

A large new field of epidotic-magnetitic rock, probably related to the Llanganates skarn, was visited west of the Río Verde, on the hill between the Río Verde and the Río San Jorge at an altitude of over 2100 m (Río Verde Sheet, 8020-98465). It appears that the tectonic foliation is subhorizontal, as in other cases of the Llanganates skarn (Litherland, 1989), although we did not see 100% certain outcrops. It is very difficult to use aerial photographs to determine the extension of this unit.

The rocks are fine-grained to fine-to-medium-grained, rich in epidote. They are massive and without penetrative tectonic foliation. Some are rich in magnetite. Below, there are schists and metadiorites with subvertical tectonic foliation.

2.7 The Subandean Belt

Studies of the subandean zone along the Baeza - Río Salado road indicate that there is a transition of 100-200 m in thickness between the Hollín and Napo Formations, a transition of orthoquartzites/sandstones intercalated with black shales and volcanics.

3. ECONOMIC GEOLOGY

- (a) Gold was panned in the Río Verde de Pastaza and in the Río Topo.
- (b) Some samples from the new skarn field of the Río Verde indicate a strong presence of magnetite.
- (c) Ophiolitic outcrops with possible potential for precious metals were located.
- (d) Another skarn-type field was located, which represents a zone of mineral potential.

4. REFERENCES

GUZMÁN J. (1986) Hoja Geológica de San José de Poaló, escala 1:100000, Instituto Ecuatoriano de Minería (INEMIN).

KENNERLEY J. B. (1971) Geology of the Llanganates area, Ecuador, Rep. Inst. Geol. Sci., London, No. 01.

LITHERLAND M. (1987) Proyecto Geológico Cordillera Real, Primer Informe Anual, INEMIN-Misión Británica.

LITHERLAND M. (1988) Proyecto Geológico Cordillera Real, Segundo Informe Anual, INEMIN-Misión Británica.

LITHERLAND M. (1989) Proyecto Geológico Cordillera Real, Tercer Informe Anual, INEMIN-Misión Británica.

Dr. Martin Litherland

LEADER OF THE BRITISH MISSION



No. 10296

QUITO, DECEMBER 13, 1989

TO : GERENTE TÉCNICO

FROM : DR. MARTIN LITHERLAND

SUBJECT : Technical Report of geological works for the Monte Olivo-Río Condué section and the Río Minas area, Carchi and Napo Provinces, from October 09 to 27.

1. INTRODUCTION

1.1 Project context

The Geological Technical Cooperation Project between the governments of Ecuador and Great Britain involves the collection of field data to understand the geology of the Cordillera Real. This aims to establish a model of its formation processes, as well as its relationship with environments that govern potential mineral resources for future local works concerning the Instituto Ecuatoriano de Minería.

1.2 Objectives

The commission that is the subject of this report was carried out from October 09 to 27, 1989. The objective was to study the metamorphic rocks of San Gabriel-Río Minas and to perform a geological section from Monte Olivo to La Sofía along the Río Condué.

Due to access difficulties and slow progress along the Río Condué, it was not possible to continue to La Sofía.

1.3 Assigned personnel

Dr. Martin Litherland (ODA/BGS)
Sr. Manuel Céleri (INEMIN)
Sr. Mario Núñez (INEMIN)

1.4 Transport

Land Rover Jeep, license plate AT-0240, from the British Mission.



1.5 Detailed activities

Month	Day	Traverse
October	09	Quito – Ibarra
	10-15	Studies around San Gabriel-Río Minas, search for labourers in Monte Olivo, shopping
	16-26	Ibarra – Monte Olivo – Río Condué – Ibarra
	27	Ibarra – Quito

1.6 Geography and vegetation

For the Monte Olivo-Río Condué section, it is necessary to ascend from Monte Olivo (2400 mamsl) through the páramos of the Cordillera de Maynas (3700 m), descending through montane forests along the Río San Jorge to the Río Condué (2500 m).

1.7 Access

In the San Gabriel – Río Minas sector, there is an abundance of passable roads. For the Monte Olivo – Río Condué section, there is Jeep access only as far as Monte Olivo; after that, there is a mule track that reaches the páramo. Descending the Río San Jorge, there is an old trail which disappears by the Río Condué.

1.8 Work methodology

The methodology is indicated in Litherland (1987). The following were collected:

Heavy mineral samples	10
Fluvial samples	3
Petrographic samples	37

1.9 Previous works

The San Gabriel-Río Minas area (Chamizo Grande) was studied in the compilation of the San Gabriel Geological Sheet (Salazar et al., 1986), but the Monte Olivo-Río Condué section was not completed in that study.

The accessible metamorphic rocks of the San Gabriel Sheet were also studied by Litherland and Bermúdez (1987), which was included in the First Annual Report of the Cordillera Real Project (Litherland, 1987).

To the south, the Mariano Acosta geological sheet was compiled by Santamaría and Sierra (1988).



2. GEOLOGY

2.1 Introduction

As the basement geology occurs in discrete belts with an approximate NE strike, it will be convenient to provide a description of the units from west to east.

2.2 The basement to the west of Monte Olivo

This comprises outcrops of the Pimampiro granodiorite, metapsammites, amphibolites, and pelitic schists (Map 2) (Litherland and Bermúdez, 1987), which fall within the Central belt of the Metamorphic Complex of the Cordillera Real (Litherland, 1987).

2.3 Monte Olivo schists and paragneisses

This pelitic schist belt, followed to the east by semipelitic gneisses, can be traced from Monte Olivo (Map 2) to the Río Minas sector (Chamizo Grande) (Map 1) and further north to El Playón (Litherland and Bermúdez, 1987).

The schist belt is essentially composed of muscovite $\pm$ garnet pelitic schist, with zones or bands of graphitic schist and bands of fine- to medium-grained orthoquartzite. The garnets can reach a size of 2 cm.

The contact with the paragneiss belt to the east is transitional and represents a more psammitic sequence. This contact is indicated to the east of Monte Olivo, going up the trail, and to the east of the Río Minas, going up the Quebrada Juan Ibarra. The paragneiss is marked by the presence of muscovite, garnet, and a medium- to coarse-grained quartz-feldspathic component. Float blocks indicate a strong semipelitic component composed of intercalations of orthoquartzite and schist on a scale of 1-5 cm.

There are also zones of pelitic schist and orthoquartzite. Amphibolites are rare, but there are small outcrops with greenstones, which indicate syn-tectonic intrusions. The schists and paragneisses have a strong tectonic schistosity.

2.4 The “pegmatitic” zone of Monte Olivo

The mineral potential of this zone deserves its description under section 3.3 (Mineral potential).

2.5 Maynas granodiorite

This unit outcrops throughout the páramos of the Cordillera Maynas. The lithology is uniform and comprises medium-grained (meta)granodiorite with biotite megacrysts up to 2 cm long; the alignment of which identifies a tectonic foliation in the rock to form an orthogneiss: the more deformed the rock, the stronger the biotitic foliation. Mafic xenoliths have been noted.

Minor lithologies seen in float blocks are: metadiorite, undeformed pegmatitic veins up to 10 cm wide with hornblende crystals up to 5 cm, and hornblendite seen in small float blocks.

The Maynas granodiorite is identical, up to the hornblende pegmatite zone, to the Chingual and Sacha metaplutons (Litherland and Bermúdez, 1987) which outcrop along the El Playón-La Bonita road, and likely forms a single metaintrusive body with them. The provisional Rb-Sr age for the Chingual pluton is around 156 Ma (Litherland, 1988).

2.6 The Condué granite

This plutonic body outcrops below in the Río San Jorge and along the Río Condué until the end of the section.

The typical lithology is a pink, coarse- to very coarse-grained alkali granite, with prominent K-feldspar and no deformation. There is only a strong jointing with a strike of 70°. The rock is leucocratic with weak biotite development, and there are aplitic and pegmatitic phases without biotite, in which the quartz can reach 1.5 cm in size. Xenoliths are absent. Some blocks in the Río Condué show a medium- to coarse-grained granite with K-feldspar megacrysts up to 5 cm long.

Near the junction of the Condué and Río San Jorge, there are outcrops of a pale, medium-grained granite with a bit more biotite, which is mixed in some places with the dominant pink type and may represent an early phase of the intrusive.

The Condué granite can be correlated with the El Gato granite of Santamaría and Sierra (1988) in the Mariano Acosta Sheet.

2.7 Minor intrusions

In some outcrops, the Condué granite is cut by irregular porphyry intrusions or rhyolite dikes up to 3 m wide. The strong jointing cuts both the granite and the minor intrusions. To the west, there are also minor acidic intrusions cutting the Monte Olivo paragneisses.

Thus, it is possible that the minor acidic intrusives are related to the final phase of the Condué granite.

2.8 Serpentinities

One day was spent searching for serpentinite float blocks in the Chota-Ambuquí Valley area, but the results were negative. It seems that the Peltetec ophiolite does not continue through this sector.

We also went to San Gabriel to investigate reports of a small carving industry using serpentinite. We eventually discovered a green serpentinite float block in a workshop, but we did not find its location in the field. There are no serpentinite blocks in the Río Minas, and if the source is in Ecuador near San Gabriel, it could be a basement “window”.



3. ECONOMIC GEOLOGY

3.1 Occurrences of metallic minerals

3.1.1 Gold

Map 1 indicates that gold was panned at all three sampling stations. In the Río Minas, there were 12 flakes in the pan, some up to 1 mm. In the Quebrada Juan Ibarra, there were four flakes, and one in the Quebrada Mueses. It should be noted that it is almost certain that the gold in the two creeks comes from the metamorphic basement and is possibly associated with the “pegmatitic” belt. The gold in the Río Minas may also come from the metamorphic basement.

3.1.2 Copper

There are the following indications of copper mineralization:

- (a) An occurrence from a new excavation on the north side of the road, 100 m before reaching the El Carmen River bridge heading east from Monte Olivo. In a 10 cm wide mylonitic zone, which also has abundant calcite, there are surfaces rich in green chrysocolla. The surrounding lithologies are pelitic and graphitic schists, and amphibolites.
- (b) East of Monte Olivo, upstream in the San Miguel River, there are small quartz vein float blocks with veinlets of pyrite-chalcopryrite-chrysocolla, which likely come from the Maynas granodiorite.
- (c) In the Río San Jorge, there are blocks of the Maynas granodiorite with minor Cu mineralization in quartz veins along joint planes.
- (d) A rare float of medium- to coarse-grained muscovite granitoid orthogneiss in the Río Condué contains small specks of sulphides and Cu mineralization 2 mm in size, elongated by tectonic foliation.

3.1.3 Iron

- (a) A float block in the Río Minas contains magnetite tectonic lenses/ellipsoids up to 1 cm long in a medium-grained quartz-feldspathic matrix. The magnetite could be of nodular origin, but it is most likely a tectonic boudinage. The rock contains around 15% magnetite.
- (b) In the Río Condué, small disseminations of magnetite occur within a 5 cm wide pegmatitic segregation inside a Condué granite float.

3.1.4 Titanium

Rutile megacrystals (TiO_2) (confirmed by XRD analysis) occur isolated within a medium-grained paragneiss near Monte Olivo (Map 2). The crystals measure up to $4 \times 3 \times 2$ cm and are red and translucent with a hardness of around 6 and good cleavage. The crystals are associated with small pegmatitic pockets (feldspathic?) and the occurrences fall within the “pegmatitic” belt of Monte Olivo. This occurrence of rutile megacrystals is interesting from a collectors’ point of view, but not in the sense of titanium deposits.

3.2 Occurrences of non-metallic minerals

3.2.1 Mica

Muscovite “books” up to 5 cm in size are found in the “pegmatites” in the Río Minas area (Map 1) and up to 3 cm in the “pegmatites” east of Monte Olivo.

3.2.2 Ornamental Stone

The Condué granite has a phase with K-feldspar megacrysts up to 5 cm long within a coarse-grained matrix.

3.2.3 Tourmaline

This mineral is common throughout the “pegmatitic” belt in the Río Minas (Map 1) and Monte Olivo (Map 2) sectors, where crystals reach sizes of 3 cm long. However, the tourmaline is of the schorl type and it seems there is no potential for the semi-precious gem industry.

3.2.4 Zoisite

Elongated crystals of semi-translucent green zoisite (confirmed by XRD analysis) up to 4 cm long were found within quartz veins in the “pegmatitic” belt near Monte Olivo (Map 2). They are of interest to collectors.

3.3 Mineral Potential

3.3.1 The Monte Olivo pegmatitic zone

Ascending the trail east of Monte Olivo (Map 2) through the schist/paragneiss transition zone, the presence of tourmaline and megacrystals of muscovite, zoisite, and rutile is found in “pegmatized” type schists/paragneisses.

Ascending east of the Río Minas (Chamizo Grande) (Map 1), pegmatite float blocks are found which come from the same schist/paragneiss transition sector. The pegmatite shows large crystals of smoky K-feldspar which reach up to 10 cm, but for the most part they are destroyed by a secondary texture of white quartz/feldspar of reduced grain size, to the point that some samples resemble aplites. Some textures resemble greisen.

The pegmatites/aplites carry tourmaline, large muscovite sheets, and in some examples, small garnet crystals. Some blocks have a tectonic foliation and can be related to a syn/post-tectonic event.



A pegmatitic belt can be proposed from Monte Olivo to the Río Minas, corresponding to the schist/paragneiss transition zone for a distance of 20 km, supported by the presence of pegmatite float in the El Carmen River, which comes from north of Monte Olivo.

There are also pegmatite blocks near the Blanco River bridge in Sigsigpamba, which may indicate an extension of the pegmatitic belt for another 10 km further south, while the existence of pegmatite blocks in the Río Minas (Map 1) indicates a probable extension of the belt further north.

Thus, the Monte Olivo pegmatitic belt is a regional zone possibly related to high levels of the Tres Lagunas granite belt, which, to the south in the Cordillera Real, can carry tourmaline and traces of Sn-W mineralization (Litherland, 1988).

The mineral potential of the Monte Olivo pegmatitic belt is still unknown due to a lack of studies. It is worth noting the presence of tourmaline, mica, and garnet, and the minerals zoisite and rutile, as well as the possibility that the area is a source of gold. However, no sample from the area shows anomalous radioactivity by scintillometer, and there are no reports of mineralization for a relatively accessible area.

3.3.2 Conclusions

Apart from a mineral potential related to the Monte Olivo pegmatitic belt and an alluvial gold source from the Río Minas, it seems that the sectors further east are sterile. The Maynas granodiorite and the Condué granite only show small-scale Cu and Fe mineralization.

4. REFERENCES

LITHERLAND M. (1987) Cordillera Real Geological Research Project: First Annual Report, INEMIN-Misión Británica, Quito (Unpubl).

LITHERLAND M. (1988) Cordillera Real Geological Research Project: Second Annual Report, INEMIN-Misión Británica, Quito (Unpubl).

LITHERLAND M. y BERMÚDEZ R. (1987) Informe Técnico Ibarra-Tulcán. INEMIN, No. 0265, no publicado.

SALAZAR E., CILIO E. y DÍAZ L. (1986) Mapa geológico de la Hoja San Gabriel (1:100000). INEMIN.

SANTAMARÍA W. y SIERRA J. (1988) Breve explicación de la Geología de la Hoja Mariano Acosta (1:100000). INEMIN.

Dr. Martin Litherland
LEADER OF THE BRITISH MISSION
cc. International Missions

No. 01270

QUITO, MARCH 06, 1990

TO : GERENTE TÉCNICO

FROM : DR. MARTIN LITHERLAND

SUBJECT : Technical Report of geological works in the La Bonita, La Sofía, and Puerto Libre zones, Sucumbíos Province, from January 09 to February 02, 1990.

1. INTRODUCTION

1.1 Project context

The Geological Technical Cooperation Project between the governments of Ecuador and Great Britain involves the collection of field data to understand the geology of the Cordillera Real, aimed at establishing a model of its formation processes; likewise, its relationship with the environments that govern potential mineral resources for future local works concerning the Instituto Ecuatoriano de Minería.

1.2 Objectives

The commission that is the subject of this report was carried out from January 09 to February 02, 1990. The objective was to study the metamorphic and plutonic rocks of the La Bonita-La Sofía-Río Cofanes and La Bonita-Puerto Libre sectors.

This commission fulfilled its scheduled objectives.

1.3 Assigned personnel

Dr. Martin Litherland (ODA/BGS)
Sr. Laureano Saltos (INEMIN)
Sr. Mario Núñez (INEMIN)

1.4 Transport

Jeep Land Rover, license plate AT-0274, from the British Mission.



1.5 Detailed activities

Month	Day	Traverse
January	09	Quito (shopping) - El Higuerón
	10	Hiring of day labourers in La Bonita
	11-22	Metamorphic studies in La Bonita, Valle Negro, La Sofia, Rivers: Cofanes, Laurel, Condué, San Jorge.
	23	La Sofia - La Bonita
	24-30	La Bonita - Puerto Libre
	31	Puerto Libre - Lago Agrio - Quito
February	1-2	Puerto Libre - Lago Agrio - Quito

1.6 Access

The new El Carmelo - La Bonita road has already reached El Higuerón, and the pilot road reached La Bonita during the commission. There is a trail road between La Bonita - La Sofia and La Bonita - Puerto Libre. There are cable cars (tarabitas) to cross the Cofanes and Laurel rivers (near La Sofia) and the Chingual river (near El Recodo Creek). Further down, on the Cofanes, we used a plastic boat to cross the river.

1.7 Work methodology

The methodology is indicated in Litherland (1987). The following were collected:

Heavy mineral samples	15
Fluvial samples	15
Petrographic samples	48

1.8 Previous works

Most of the study area belongs to the San Gabriel geological sheet (Salazar et al., 1986). To the north, La Bonita was also the subject of study by Litherland and Bermúdez (1987). The Río San Jorge sector is included in the Mariano Acosta sheet (Santamaría and Sierra, 1988). A reconnaissance study of the Cofanes and Chingual rivers was carried out by Moreno and Viteri (1979); Vera (1980) conducted a study on the occurrence of uraniferous phosphorite in the Chingual River.

2. GEOLOGY

2.1 Sedimentary and metasedimentary rocks

2.1.1 Paragneiss

Fine to medium-grained paragneiss with biotite and muscovite is found in the form of boulders originating from the NW of the mylonitic zone of the Cofanes fault.

2.2.2 “Chert”

North of Rosa Florida, west of the Rosa Florida fault, there are outcrops of “chert” with black slates and little deformation or alteration. The rock shows stratification laminations of “chert” (pale), slate (black), and sulphides.

The same formation continues to the SW, as is evident in the form of boulders in the Río Palmar and the Industria and Las Juntas creeks. These boulders show fine interlaminated siliceous rocks of pink, pale, and pale green and black colours, with feldspathic alterations, in places featuring pink feldspar (adularia?).

The same lithologies are also found as boulders in the La Sofía sector, in the Cofanes and Laurel rivers and the Quebrada Chisparosa, indicating the repetition of the formation further west (probably through tectonic imbrication). In these boulders, the chert is also altered by epidotization and feldspathization, along with calcareous bands and others rich in ?garnet.

The “chert” is a guide horizon for the sector. The outcrops north of Rosa Florida appear to be of sedimentary origin, but for the other sectors, a siliceous volcanic protolith is possible.

2.1.3 Marble

There are blocks of medium-grained grey marble in the Río Cofanes.

2.1.4 Cretaceous Formations

Limestones and black shales of the Napo Formation and sandstones and red mudstones of the Tena Formation outcrop in the south. Septarian nodules occur in the Napo Formation.

2.2 Granitoid and metagranitoid rocks

2.2.1 La Bonita pluton

The town of La Bonita is located on a granodioritic-tonalitic plutonic body with biotite, with or without hornblende. For the most part, the rock is tectonically foliated with oriented minerals, and near the La Bonita and Cofanes faults, a mylonitic gneiss with “augen” type phenocrysts is found. Its extent to the south is unknown.

Another body of similar composition has been interpreted in the Valle Negro sector (La Bonita-La Sofía). A repetition of the La Bonita pluton is assumed due to tectonic imbrication.



The dominant rock is granodiorite-tonalite, but there are minor lithotypes such as diorite, gabbro, and hornblendite which are found as rounded boulders. In sections and boulders south of the Quebrada Resbalosa, dioritic phases converted to amphibolite by shearing are noted. In the same sector, an abundance of mafic xenoliths is observed; the freshest ones are of andesitic porphyry (greenstone). There is also evidence of mafic dikes.

The La Bonita pluton is similar in lithotectonic aspects to the Chingual pluton further north (Litherland and Bermúdez, 1987) which was dated by Rb-Sr at 156 ± 21 Ma (in Litherland, 1988).

2.2.2 The Condué pluton

An alkaline granite (biotitic monzogranite), pink to grey, without tectonic foliation, was located along the Río Condué upstream (Litherland, 1989). In the current commission, the Río Condué was visited at its confluence with the Río Cofanes. There are outcrops of a similar granite there, which also dominates the lithologies of rounded boulders. Thus, the Condué granite is interpreted to exist throughout the Río Condué.

The pluton also crops out west of the La Sofía fault in the Río Laurel, and in the Río Cofanes upstream from the confluence of the Río Condué. There are also boulders of the granite in these rivers and in the quebradas Pilares and San Jorge further south, indicating the great extent of the pluton.

Around the La Sofía area, the outcrops and boulders of the granite are grey to white in colour and medium to coarse-grained in size. Xenoliths are absent with the exception of some blocks in the Río Cofanes with xenoliths rich in fine biotite, partially assimilated. There are also minor felsic or porphyritic intrusives up to 2 m thick.

Boulders in the Quebrada Pilares indicate a grey granite with small biotitic xenoliths, a coarse pink granite with K-feldspar tablets, and a medium-grained granite with agmatitic structures of volcanic xenoliths and andesitic greenstones, the two lithologies being essentially undeformed.

2.2.3 The Rosa Florida pluton

This is located in the Rosa Florida sector and to the south as far as the Río La Chispa. The lithologies are dominated by a high percentage of feldspar, whether of plutonic or subvolcanic lithotype, and with little free quartz content (estimated between 0% and 15% with a hand lens). The igneous rocks have granular textures and lack igneous or tectonic foliation. From the north (Rosa Florida) to the south (Río La Chispa), the igneous lithologies decrease in grain size from coarse-grained plutonic rocks to medium-grained rocks mixed with porphyries and agglomerates. South of the Río La Chispa, medium to fine-grained rocks dominate, with agglomerates, and are named as “Misahuallí” volcanics on the map, but in the field, it is realized they are a single entity rising from north to south from plutonic to subvolcanic to volcanic levels.

In the north, the coarse-grained plutonic rocks are dominated by quartz monzonites with biotite with or without hornblende. Further south, approaching the Río La Chispa, the dominant rocks are micromonzonites and microsyenites. The syenites have a strong pink colour due to the high K-feldspar content.

In the outcrops of the Quebrada La Industria, the quartz monzonite contains green rock xenoliths up to 5×4 cm with signs of epidotization, and in the same creek, there are boulders of epidote rock and skarn. In other outcrops, there are green rock dikes, and it is likely that this mafic phase was intruded into the monzonitic magma: autobrecciation.

2.3 Volcanic and metavolcanic rocks

2.3.1 “Misahuallí” volcanics of the Río La Chispa

In the Río La Chispa, there are boulders of agglomerates, acid porphyries, and tuffaceous sandstones indicating a volcanic complex at high levels of the Rosa Florida pluton. These volcanic rocks continue further south to the La Barquilla fault and also include banded green tuffs and green rocks with epidotic orbicular structures.

In the Río La Chispa, the agglomerates show volcanic and syenite clasts. The elongation of clasts is due to compaction because the more competent ones are not deformed.

These volcanics can be correlated with the Misahuallí volcanics of Jurassic age.

2.3.2 Volcanics with cleavage

Along the new road north of La Bonita, and along part of the La Bonita-La Sofía road, and along part of the La Bonita-Rosa Florida road, there are outcrops and boulders of volcanic rocks with tectonic foliation (cleavage).

To the north of La Bonita, they are massive and cleaved volcanics of purple, green, pale, and grey colour with epidotic alteration. They are fine to medium-grained and mostly acidic in composition. There are meta-agglomerates but metasediments are absent. In some sectors, the rocks appear to be metamorphosed porphyries. There are also small sectors of metadiorite. This sequence is also exposed on the La Bonita-Rosa Florida road.

Along the La Bonita-La Sofía road, the first cleaved volcanics (Río Sucio) are pale and altered to kaolin. Along the Río Laurel, they are green and red in colour.

2.3.3 Mylonitic volcanics

These occur along the new road north of La Bonita. There is a transition between cleaved volcanics and mylonitic volcanic/plutonic rocks, accompanied by the development of feldspathic “augen” structures and the development of fine biotite and muscovite. These mylonites are found along the La Sofía fault, and south of La Bonita along the Rosa Florida fault.

2.4 Mafic and ultramafic rocks

Boulders of hornblendite and gabbro have been found, which probably represent phases of the La Bonita pluton.

Boulders of serpentinite and amphibolite were seen in the Río Cofanes upstream from the confluence with the Río Condué.

A tremolitic ultramafic schist boulder was found in the Quebrada Pilares.



2.5 Skarns

A fine-grained skarn block with epidote and garnet was found in the Quebrada La Industria. The rock resembles the Llanganates skarns of the calcic-magnetitic type, discovered further south in the mountain range.

2.6 Late minor intrusives

Along the road north of La Bonita, there is an abundance of porphyry dikes oriented subparallel to the mylonitic foliation. Only the widest ones are noted on the map.

2.7 Structural geology

2.7.1 Pre-Cretaceous structures

There are a series of faults: those affecting pre-Cretaceous rocks and those associated with regional penetrative structures, local mylonitization, and regional metamorphism.

The fundamental structures are the Cofanes, La Bonita, and Rosa Florida faults. The Cofanes fault is marked by mylonites along the Río Cofanes in the south and by mylonites at the margin of the “La Sofía fault” in the north. The mylonites show vertical mineral lineations indicating relative vertical movement along a tectonic foliation with a steep westward dip. However, along the Río Cofanes, the mylonites do not have a strike parallel to the fault, likely indicating a late stage of rejuvenation.

The La Bonita fault also shows mylonites with structures steeply inclined to the west.

The Rosa Florida fault dips at a lower angle to the west and divides rocks with tectonic foliation (to the west) from undeformed rocks (Rosa Florida pluton) to the east. For this reason, it is considered the “cratonic front” during the “Jurassic” tectonic event.

The faults can be interpreted as a series of thrusts with eastward movements. Associated minor folds have subhorizontal axes.

The Sofía fault, which divides the Condué granite and the metamorphic rocks, may also be of pre-Cretaceous age. The Sofía fault (strike 40°) follows the Cofanes-Sofía fault (mylonitic belt) for part of its course. The rocks beside the fault have drag joints with strikes of approximately 350° and 100°; one of the latter shows sinistral movement. This joint movement may indicate dextral movement along the Sofía fault, which (according to Moody and Hill, 1956) is the same direction indicated by the regional displacement of the mylonites.

2.7.2 Post-Cretaceous structures

Direct evidence for post-Cretaceous movements is found in the Cretaceous formations. In the La Barquilla fault zone, a subvertical cleavage is imposed on the rocks of the Napo Formation with slickensides indicating vertical movement. This structure can be interpreted as a reverse fault.

Further south, where the Cretaceous Formations are essentially subhorizontal and without cleavage, the Puerto Libre fault thrusts the Napo Formation over the Tena Formation. This thrust fault has a low angle toward the west (Vera, 1980).

2.8 Provisional geological history

- (1) The La Bonita granodiorite and the Rosa Florida pluton intrude their volcanic effusives in Jurassic times.
- (2) Tectonism (collisional?) produced a series of eastward thrusts as far as the Rosa Florida fault (craton boundary) associated with mylonitic zones and regional metamorphism.
- (3) Intrusion of the Condué granite (Jurassic?) which cuts the mylonites.
- (4) Sofía Fault (dextral).
- (5) Deposition of the Cretaceous Formations.
- (6) Puerto Libre and La Barquilla faults; intrusion of minor porphyries.

3. ECONOMIC GEOLOGY

3.1 Occurrences of metallic minerals

3.1.1 Gold

There are gold placers in the Río Cofanes below La Sofía and in the Puerto Libre sector, where the town of about 30 families is dedicated to mining, and where there are operations by the Arajuno mining company of Ing. Esteban Crespo.

According to Mr. Narváez from La Sofía, the alluvial gold below La Sofía was discovered in 1979 after a period of bad weather and landslides. In this sector, nuggets of up to 30 g have been found. Mr. Narváez said that the gold comes from the Río Cofanes upstream from the confluences with the Condué, Tigre Grande, and San Antonio rivers; that is, from its headwaters. According to our studies, the four rivers that form the Río Cofanes above La Sofía have alluvial gold. However, of these four, there was more gold in the Río Laurel than in the Cofanes (see proportion of sparks: pans on the map). We also panned gold in the Río San Jorge and in the Río Palmar (tributary of the Chingual River).

We also panned gold from the alluvial terrace of approximately 60 m in thickness which occupies the Río Cofanes valley in the La Sofía sector.

3.1.2 Copper

Traces of Cu mineralization have been noted in the following localities:



- (a) In the Río Cofanes downstream from La Sofía, there are quartz veinlets (10 cm) concordant with the mylonitic foliation in the granodiorite. In one of them, there are traces of chalcopyrite with biotite crystals up to 1 cm in size.
- (b) In the Río Cofanes upstream from La Sofía, there was a boulder of mylonitic rock with pyrite and chalcopyrite in veinlets that follow the foliation (syntectonic mineralization). A similar rock was found south of the Río Sucio (No. 662) but chalcopyrite was not noted.
- (c) There are bands of metallic mineral up to 3 cm wide with chalcopyrite and sphalerite? in boulders of feldspathized “chert” in the La Industria Creek. These “cherts” always carry pyrite/chalcopyrite? mineralization where they occur as outcrops or boulders.
- (d) North of La Bonita along the new road, there is a small occurrence of chalcopyrites in siliceous metafelsic rocks in contact with a Tertiary porphyry intrusive. The presence of pyrite is notable in the metavolcanics of that sector, especially in epidotized drag veins.
- (e) Small Cu mineralization (covellite?) associated with pyrite and hematite is found in a quartz-epidote vein 10 cm thick in a monzonite boulder in the Las Juntas Creek.

3.1.3 Uranium

The uraniferous phosphorite outcrop (Vera, 1980) was confirmed in the Chingual River. The scintillometer anomaly was 320 cps with a background of 80 cps; Vera measured 440 cps.

3.2 Occurrences of non-metallic minerals

3.2.1 Asbestos

The presence of amphibole asbestos along shear surfaces in mafic rocks is common, e.g., epidotized greenstone boulders in the Río Palmar.

3.2.2 Carbonate

Besides the limestones of the Napo Formation, there are boulders of marble and massive travertine in the Río Cofanes.

3.2.3 Kaolin

The Rosa Florida pluton sector comprises feldspathic plutonic and subvolcanic rocks, and their alteration produces deposits with high kaolin/clay content.

3.2.4 Phosphate

The uraniferous phosphate outcrop of Vera (1980) was visited. The band is only 30 cm thick. Boujo et al. (1984) analyse the phosphatic potential of the region.

3.2.5 Garnet

A sample of some garnets up to 5 cm in size was seen in Puerto Libre, taken, according to the owner, from the Quebrada Culebrillas near La Bonita. This mineral is the “ruby” of the area.

3.2.6 Ornamental stone

The “syenite” of the Río La Chispa with its reddish colour and the “monzonites” (grey and pale pink minerals) could be considered in the search for ornamental stone.

3.2.7 Oil

In the Río La Chispa, and two tributaries of the Chingual River further south, there are small boulders of bituminous shale. It is assumed that the shales come from the Napo Formation.

3.2.8 Slate

Along the route north of Puerto Libre to the Río Recodo, the road goes over an elongated hill of the Napo Formation. The black slates found could be used as roofing.

3.2.9 Gravel

The inhabitants of La Bonita and Rosa Florida dig pits in the weathered plutonic rocks to use as gravel on the mule tracks.

3.3 Mineral potential

The source (or sources) of gold in the Cofanes and Chingual rivers is still unknown. The field information in this report along with the results of the analyses (rock, fluvial, and heavy minerals) may shed more light on the matter.

At the moment, certain possibilities can be indicated:

- (a) Gold concentration along major shear zones (mylonites); this will be supported by the greater presence of gold in the Río Laurel, which runs along the Cofanes-La Sofia fault. Syntectonic Cu mineralization had been noted in the mylonites.
- (b) Cenozoic minor intrusives in the shear zone, subparallel to the mylonitic foliation, could also concentrate the gold. Cu mineralization had been noted at the contacts.
- (c) Concentration of gold in the altered (feldspathized) “cherts”, a lithology that always drew attention for its sulphide mineralization and the presence of K-feldspar (adularia?)
- (d) Other possibilities include skarns and serpentinites, but it seems that since each lithotype only occurs in a single river/creek, they do not have a sufficiently wide distribution.



4. REFERENCES

- BOUJO A. et al. (1984)** Proyecto Fosfatos, DGGM, Quito, no publicado.
- LITHERLAND M. (1987)** Cordillera Real Geological Research Project: First Annual Report, INEMIN-Misión Británica, Quito (Unpubl).
- LITHERLAND M. (1988)** Cordillera Real Geological Research Project: Second Annual Report, INEMIN-Misión Británica, Quito (Unpubl).
- LITHERLAND M. (1989)** Informe de comisión Monte Olivo-Río Condué y la zona del Río Minas. INEMIN No. 10296, no publicado.
- LITHERLAND M. y BERMÚDEZ R. (1987)** Informe Técnico Ibarra-Tulcán. INEMIN, No. 0265, no publicado.
- MOODY J. D. y HILL M. J. (1956)** Wrench fault tectonics. Bull. Geol. Soc. Amer., 67, 1207.
- MORENO A. y VITERI F. (1979)** Esquema geológico de la cuenca alta del Río Aguarico. INECEL, Quito, no publicado.
- SALAZAR E., CILIO E. y DÍAZ L. (1986)** Mapa geológico de la Hoja San Gabriel (1:100000). INEMIN, Quito.
- SANTAMARÍA W. y SIERRA J. (1988)** Mapa geológico de la Hoja Mariano Acosta (1:100000). INEMIN.
- VERA R. (1980)** La fosforita uranífera, Río Chingual, Chingual, Provincia de Napo. Politécnica, Monografía de Geología, Vol. No. 2, 47-55.

Dr. Martin Litherland

No. 5003

QUITO, JUNE 13, 1989

TO : GERENTE TÉCNICO

FROM : DR. JOHN ASPDEN and ING. FRANCISCO VITERI S.

SUBJECT : Technical report of the geological studies carried out between Oñacapa-Yacuambí; and Jimbilla-Río Quimi from April 11 to 29, 1989.

1. INTRODUCTION

1.1 Project context

Within the Technical Cooperation Agreement being carried out by the Governments of Ecuador (INEMIN) and Great Britain (ODA-BGS), the collection of field geological information is contemplated to allow for the understanding of the geology of the Cordillera Real. This is aimed at establishing a model of its formation processes, as well as its relationship with the environments that control potential mineral resources for future detailed local work.

1.2 Objectives

The commission that is the subject of this report was carried out from April 11 to 29 of the current year. Its objective was to conduct a geological study in order to confirm or discuss the existing model in the south of the country. This walking traverse study was carried out by two groups: the first from the town of Oñacapa, along the left bank of the Río Negro to Yacuambí, and the other from Jimbilla (Loja Province)-Los Guabos, along the left bank of the Río Sadal and Río Quimi.

1.3 Assigned personnel

To carry out this work, it had to be performed in two groups in order to cover the geological area of interest more extensively across two sectors: (a) the sector comprised between Oñacapa-Río Negro-La Florida-Yacuambí and (b) Jimbilla-Río Sadal-Río Quimi.

Group No. 1	Jimbilla-Río Sadal-Río Quimi Ing. Francisco Viteri
Group No. 2	Oñacapa-Yacuambí Dr. John Aspdén Sr. Manuel Céleri
Driver:	Sr. Washington Cevallos



1.4 Means of transport

A Land Rover Jeep from the British Mission, plate AT-0056, was used as the means of transport.

1.5 Detailed activities

The collection of geological field information was carried out according to the following schedule of activities:

Group No. 1

Month	Day	Traverse
April	11	Quito-La Toma
	12	Loja-Jimbilla
	13	Jimbilla-Los Guabos
	14	Los Guabos-Río Cristal
	15	Río Cristal-Río Verde
	16	Río Verde-Cordillera Chivato
	17-18-19	Cordillera Chivato-Unión Sadal
	20	Unión Sadal-Headwaters of the Río Sadal
	21-22-23	Left bank of the Río Sadal
	24-25	Quebrada Honda
	26	Río Negro
	27	Río Quimi and Unión Río Negro (rescue site)
	28	Loja
	29	Loja-Quito

Group No. 2

Month	Day	Traverse
April	13	Loja-Masaca-Las Juntas-Saraguro
	14	Saraguro-Oñacapa-H. Aguarnuda
	15	H. Aguarnuda-Río Quingueado
	16	Río Quingueado-Río Negro
	17	Río Negro-La Florida
	18	La Florida-Chivato
	19	Chivato-Río Ingenio
	20	Río Ingenio-Río Garcelán
	21	Río Garcelán-Yacuambí-Zamora
	22	Zamora-Loja
	23-28	Loja (period used for planning and search for the rescue of Ing. F. Viteri S.)
	29	Loja-Quito

1.6 Geography and hydrography

In the northern sector, high páramo areas predominate with altitudes ranging between 3000-3300 mamsl. These areas are flat and slightly irregular, featuring small hills such as Piedras and Gavilán. Moving toward the eastern part, the terrain becomes very steep, with the Sushano Range serving as a topographical landmark, reaching very close to the town of Yacuambí.

Regarding the southern part of the study area, there are several important topographical features; consequently, the relief in the cross-section performed is very irregular. Among the metamorphic features, we find the Los Guabos and Sharan ranges, the Chivato and Sadal ranges, and the Sadal Ridge. In these sectors, the relief is very rugged with vertical slopes.

Concerning the hydrography in the north of the study area, there are two well-known drainages in the highlands: the Río de La Plata (Río Negro) and the Quingueado. These drain into the sub-Andean zone, later taking the names Garcelán and Ingenio rivers, which eventually drain into the Río Yacuambí.

In the south of the study area, until just before turning at the Chivato Range, all drainages (rivers and creeks) flow toward the south, meaning toward the Zamora River (Loja Norte topographic map).

On the other side of the Chivato Range, the main rivers flow toward the north and then to the east; among these are the Sadal, Sordomoros, and Peñas Encantadas rivers, which, joined with the Río Negro that flows from south to north, form the Río Quimi.

1.7 Climate

The mentioned topographical conditions have an impact on the region's climate, which ranges from cold and frigid in high areas to temperate in low areas.

Regarding cold climates with sub-zero temperatures, these correspond to sectors between 3000-4000 mamsl, characteristics present at Cerro Piedras in the north, and in the south at the Chivato Range and Sadal Ridge.

For a temperate climate, the eastern flank of the Cordillera Real can be considered, with temperatures from 12 to 20°C. This corresponds to sectors between 1000-3000 mamsl, where the towns of Yacuambí, Chivato, and Quimi are located, as well as the entire valley of the Quimi, Ingenio, and Yacuambí rivers.

1.8 Access

To reach Yacuambí from Oñacapa (Tambo-Pamba), a bridle path is taken which passes by the Aguarnuda River. It is necessary to climb to 3200 mamsl to reach the headwaters of the Río Quingueado, then a main path must be taken to descend to the Río Negro and continue down toward the Río Ingenio, very close to the town of Yacuambí.



For the traverse to the south of the study area, a bridle path had to be taken from Jimbilla to Los Guabos; then, a very difficult trail was taken on foot. Up to a ridge formed by the Tibio and Cristal rivers, there are small paths and trails made in recent days, as well as ancient paths. Therefore, it was necessary to continue further north to reach the Río Verde and arrive at the Río Negro via an old trail, advancing to the Chivato Range. Unfortunately, this was impossible due to two very serious problems: the weather and the fall of a worker. From this point (Chivato Range Ridge), we were able to locate a house in the distance at the Sadal Junction (Las Juntas topographic map); this partly helped us continue further northeast, thus avoiding the crossing of the Sadal Range and allowing us to continue to the Río Negro.

Following the Río Sadal, a very dangerous traverse began, opening a trail in some sectors with steep slopes until reaching the site called the Sadal Junction (Las Juntas topographic map). We then followed the left bank of the Quimi River, also opening a trail, and arrived after fifteen days of walking at the junction of the Quimi and Negro rivers.

1.9 Previous works

Very close to the northern part, several studies have been carried out by the Project and other authors as follows:

- The Saraguro topographic sheet exists, completed by J. B. Kennerley (1969-1972) at a 1:100000 scale. He conducted a reconnaissance near the study area, mainly in the sectors known as Tres Lagunas, west of Saraguro.
- Likewise, Dr. J. B. Kennerley and Ing. Almeida (1969-1970) carried out local geological studies up to the Jimbilla area. No other previous works exist from this point to the Quimi River, as indicated on the Loja geological sheet, scale 1:100000.
- Project members Aspden, J. and Viteri, F. (1987) carried out a geological traverse from Oña-Loma Voladora-Yacuambí, and in November 1988, another traverse from Nabón-Shingata-Tutupali.

2. GEOLOGY OF THE SECTOR BETWEEN OÑACAPA-YACUAMBÍ (MAP No. 1)

2.1 Introduction

The geological traverse carried out from the sector known as Oñacapa to very near Yacuambí is disappointing, because a large part of the bridle path follows the highlands. Consequently, outcrops are very limited, and when rocks are present, they are highly weathered. However, the regional distribution of the rock units has been established, and this information will represent a contribution to our previous knowledge.

2.2 Cenozoic Volcanics (in the west) with Cu

These rocks are extensively developed in the western part of the studied area. They have not been studied in detail, but consist mainly of felsic acid tuffs and also include intermediate to acid lavas and agglomerates. According to Baldock (1982), the Cenozoic volcanics belong to two main Formations: the Saraguro and the Tarqui Formation.

Continuing east, near Cerro Piedras, there are smaller quantities of felsic tuffs and andesitic-dacitic lavas which were observed along the path. In the eastern part of the Río Negro, there are good exposures of these volcanic rocks. The degree of weathering of these rocks is strong, and they possibly include some high-level intrusive material. These rocks are tentatively assigned to the Cenozoic.

2.3 Rocks of the metamorphic complex

2.3.1 Tres Lagunas suite (XgTL)

As reported in previous reports, the Tres Lagunas Unit typically consists of granite/granodiorite with biotite, foliated with potassium feldspar megacrystals.

In this traverse, this unit is heavily weathered, and the best examples of this unit were observed as boulders at Cerro Piedras and in many of the streams and creeks, for example, in the Río Quingueado (Saraguro Sheet 1:50000).

To the east of the main batholith along the trail, small outcrops (windows or apophyses?) of the Tres Lagunas unit were observed within what we consider the Loja division (see Map No. 1). The recorded foliations were few, but generally have a strike following the mountain range with dips steeply inclined toward the west.

According to previous photogeological interpretations, the existence of two prominent circular depressions along the western margin of the Tres Lagunas unit had been determined (see Map No. 1). The one located furthest west in the upper part of the Río Pichanal was visited during this traverse, but unfortunately, the weather conditions were very poor and the attempt to reach the eastern depression, which is the better developed of the two, was cancelled.

In the Pichanal depression, there are very few outcrops, but Tres Lagunas granite boulders are very common. In one sector, a possible outcrop was sampled, consisting of a fine-grained granite with a sugary texture (aplite), which carries long quartz crystals in the form of eyes. This rock is considered a variation of the Tres Lagunas unit in which the original plutonic texture has been destroyed by late magmatic events (see section 3).

2.3.2 Loja division (DL)

As in various sectors of the Cordillera Real, the Loja division consists in this case of a mixture of pelite, semipelite, and psammite type rocks, indicating two penetrative cleavages and tight smaller-scale folds (F₂) which are generally common and have moderate to horizontal inclinations.



The relationship between the Tres Lagunas granitic unit and the Loja Division has not yet been established, but it is assumed that the original contact, which now appears foliated, was an intrusive contact.

2.3.3 Other rock types

Toward the eastern side of Chivato in the Plateado and Chivato rivers, there are boulders consisting of feldspathic porphyries with biotite (very common in the Río Plateado), biotitic granodiorite, foliated granite/granodiorite with biotite + muscovite, and andesitic lavas. We believe these types of rocks belong to the sub-Andean plutonic-volcanic complex (see 1st and 2nd Annual Reports and geological traverse reports), which are outcropping to the east.

Currently, this unit is being mapped under the assumption that it is a complex of Jurassic age, although it probably also includes younger blocks and, in particular, high-level intrusive rocks of Tertiary porphyritic type.

Jurassic plutons, and specifically the Zamora-Río Mayo batholith, are considered rock units or complexes that are including the Loja division.

In the west, at the junction of the Casatura and Pichanal rivers, there are excellent outcrops of undeformed intrusive rocks, specifically hornblende and biotite granodiorite, visible through the thick and potent Cenozoic volcanic cover. Samples from this “Pichanal” batholith have been collected for radiometric dating studies, but we assume this batholith is equivalent to the San Lucas pluton of Lower Tertiary age, which is exposed to the south along the road leading from Saraguro to Loja.

3. GEOLOGY BETWEEN JIMBILLA AND RÍO QUIMI

3.1 Introduction

This traverse, carried out from the town of Jimbilla to Quimi, does not geologically present fundamental variations regarding the existing geological-structural model in the south of the country (2nd Annual Report, Cordillera Real Project); however, there are excellent exposures of rocks, mainly semipelitic and intrusive rocks from the batholith known as Zamora-Río Mayo.

The thick vegetation on the eastern foothills of the mountain range, the climate, and the torrential rivers made it difficult to find good contacts between the different types of lithology; the extension of the traverse in length and time from 7 to 15 days, along with the lack of food, prevented greater success.

3.2 San Lucas pluton

From the town of San Lucas to the Quebrada Santa Bárbara, east of Jimbilla, there is a predominance of outcrops with a variable composition of granites to diorites, with biotite as the main mafic mineral; tonalites are also present.



This pluton was mapped by J. B. Kennerley and Almeida (1975), having an approximate area of 150 km²; now we think this is smaller, roughly around 100 km².

Diorites primarily exist in the Río Santa Bárbara; these probably represent an early phase of the intrusive. This observation is based on the fact that hornblende-rich diorites occur as xenoliths within the tonalite blocks.

Additionally, there are aplitic dykes of andesite/dolerite with variable strikes, which are common both within the intrusion and in the surroundings of the Loja division.

Several radiometric datings have been carried out as follows:

- Hall and Calle (1982) have determined ages of 52 ± 2 (biotite); 60 ± 1 (plagioclase); 61 ± 1 (biotite); 65 ± 2 (biotite); and 68 ± 2 (plagioclase).
- The Cordillera Real Project (see 2nd Annual Report) presents ages of 53 ± 2 Ma, using the Rubidium/Strontium method.

These results indicate that the San Lucas pluton is young, probably Tertiary, and the presence of foliated tonalites (Río Zenen) may indicate very recent events.

3.3 Metamorphic complex

3.3.1 Tres Lagunas suite (XgTL)

Between the Quebrada Santa Bárbara and very near the town of La Chonta, there is a thin belt of ?mylonitic rocks; these have been provisionally considered as the southern extension of the Tres Lagunas suite (see Map No. 1), taking the Oñacapa-Yacuambí geotraverse as a reference.

This thin belt consists of a quite foliated intrusive rock, where biotite can be observed as a mafic mineral; quartz and feldspar megacrystals are also present. Once thin sections and their respective analyses are available, it will be confirmed whether or not it belongs to this suite. The existing strikes in this sector, despite the outcrops being weathered, follow the mountain range (Andean) with vertical and strong dips toward the east.

Furthermore, it is important to indicate the existence of large boulders from the unit, with potassium feldspar megacrystals (10 cm) and blue quartz, in the Sadal and Peñas Encantadas rivers, which suggests the existence of good exposures at the headwaters of these rivers.

3.3.2 Loja division

This sequence of rocks is very monotonous throughout the observed extent, consisting mainly of pelites, semipelites, slates, and psammities; additionally, outcrops of green rocks (metavolcanics) were located in the Quebrada El Guabo and in the Río Cristal. This sequence mostly indicates two penetrative cleavages with Andean strikes and steep dips. The age of this division is unknown.



3.4 Intrusive rocks

From the junction of the Negro and Quimi rivers, the lithological change from the rocks of the Loja division to the intrusive rocks of the batholith known as Zamora-Río Mayo could be observed (see 2nd Annual Report, Cordillera Real Project). The contact observed locally is intrusive; these rocks extend toward the south and east.

The batholith has not been studied in detail, but based on macroscopic observations of hand samples, it consists mainly of intrusive rocks of variable composition. In this sector, the variation ranges from granodiorite to diorite, with biotite and hornblende as the main mafic minerals.

Near the contact with the Loja division, these rocks present a poorly developed cleavage, which may be due to tectonic effects. The Project has conducted radiometric dating studies on samples taken in the Napurca sector, very close to the study site; according to the results obtained using the Rb-Sr method, they yield ages of 185 Ma.

4. ECONOMIC GEOLOGY

4.1 Occurrences of metallic minerals

4.1.1 Gold

Most of the rivers and creeks were panned during the crossings; unfortunately, no significant evidence of gold could be observed. Small specks exist in the streams flowing into the Río Ingenio, and it was also possible to visit the small placer mines of the Río Yacuambí. We can also mention the significance of the existence of small specks in the concentrates of samples panned in the Quimi and Sordomoros rivers; currently, we have heavy sediment samples that will be analyzed in the future.

4.1.2 Tin and tungsten

Great emphasis is being placed on all pan concentrates from the drainages that cut through the rocks of the Tres Lagunas Unit, with the purpose of locating occurrences of tin and tungsten, characteristic elements of intrusive rocks of this type.

Previous reports from the UNDP (1972) exist, which report the presence of cassiterite and scheelite in the panned concentrates of samples collected in the Río Pichanal.

4.2 Occurrence of non-metallic minerals

4.2.1 Kaolin

Important zones of kaolinization exist within the Tres Lagunas suite very near the Río Negro, which have a high degree of weathering (see Map No. 1).

4.2.2 Tourmaline

Slightly weathered tourmaline samples were located east of the town of Oñacapa (Loja Province), associated with the granites/granodiorites of the Tres Lagunas suite; these can be observed on the path leading to Yacuambí, very near the Río Negro.

4.2.3 Graphite

There are good outcrops of metamorphic rocks on the northeastern side of the town of Jimbilla, in the Chivato Range, on the right bank of the Río Sadal, where excellent outcrops of graphitic phyllites were observed. These rocks correspond to the semipelites of the Loja Division (see 2nd Annual Report of the Cordillera Real Project).

5. REFERENCES

LITHERLAND M. (1988) Proyecto de Investigación Geológica Cordillera Real: Segundo Informe Anual, INEMIN-Misión Británica, Quito (Unpubl).

ASPDEN J. y VITERI F. (1987) Reporte de Comisión a las zonas de Saraguro – Loja, INEMIN, Quito.

KENNERLEY J. B. (1972) Hoja geológica de Saraguro, escala 1:100000, Dirección General de Geología y Minas, Quito.

KENNERLEY J. B. y ALMEIDA L. (1970) Hoja geológica de Loja, escala 1:100000, Dirección General de Geología y Minas, Quito.

UNDP (1972) Survey of metallic and non-metallic minerals (Phase II), Republic of Ecuador. Technical report No. 14. New York.

Ing. Francisco Viteri S.
INEMIN

Dr. John Aspden
BRITISH MISSION



No. 7132

QUITO, AUGUST 09, 1989

TO : GERENTE TÉCNICO

FROM : ING. FRANCISCO VITERI – CORDILLERA REAL PROJECT

SUBJECT : Technical Report of the geological works carried out between Tutupali-Ortega Alto-Río Campana Urco and Río Chuchumbleza, from June 26 to July 14, 1989.

1. INTRODUCTION

1.1 Project context

The geological research Project of the Cordillera Real, which is being carried out through a technical cooperation agreement between the governments of Ecuador and Great Britain, involves the collection of field data to understand the geology of the Cordillera Real. This is aimed at establishing a model of its formation processes, as well as its relationship with the environments that control a possible mining potential, for future local (detailed) works concerning the Instituto Ecuatoriano de Minería.

1.2 Objectives

The commission that prompted this technical report was carried out from June 26 to July 14, 1989; its objective was to conduct a geological study in the vicinity of the Cordillera de Manga Urco, at the Yacuchingari, Campana Urco, and Ortega Alto rivers. This was done with the purpose of understanding more clearly the contacts and geological characteristics between the Tres Lagunas Complex-Loja Division and the Loja Division-Zamora Batholith.

Additionally, the objective included performing geological reconnaissance at the Cantzama, Chuchumbleza, and Chicaña rivers.

1.3 Assigned personnel

To carry out this work, the commission was headed by Ing. Francisco Viteri, accompanied by Mr. Manuel Céleri as field assistant and driver.

1.4 Means of transport

Jeep Land Rover, license plate AT-0272, from the British Mission.



1.5 Detailed activities

The collection of geological information was carried out according to the following breakdown of activities:

Month	Day	Traverse
June	25	Quito – Loja (Sr. Céleri).
	26	Quito – La Toma – Loja (Ing. Viteri).
	27	Loja – Chapintza – Zamora
	28	Zamora – Chapintza – Yacuambí
	29	Yacuambí – Tutupali
	30	Tutupali – Río Yacuchingari
July	1-2	Tutupali – Río Yacuchingari
	3-4	Tutupali – Santa Cleotilde
	5	Tutupali – Ortega Alto
	6-7	Ortega Alto – Río Espadillas
	8	Ortega Alto – Río Campana Urco – Ortega Bajo
	9	Ortega Bajo – Yacuambí
	10	Yacuambí – Río Cantzama – Zamora
	11-12	Zamora – Chuchumbleza – Chicaña – Gualaquiza
	13	Gualaquiza – Cuenca
	14	Cuenca – Quito

1.6 Geography and hydrography

The studied area presents a fairly irregular relief with long and elevated divides, such as the Filo de Ortega, Filo Espadillas, Cordillera Manga Urco, Cerro Santa Clara, and Cerro San Antonio; in the eastern and western sectors, the main topographical features include: the Cordillera Voladora, Moradillas among other minor ones, and deep valleys along which torrential rivers drain, such as the Tutupali, Zavala, Santa Cleotilde, Yacuchingari, Espadillas, Campana Urco, and Paquintza, all of which flow into the Zamora River.

1.7 Climate and vegetation

The aforementioned topographical conditions have an impact on the region's climate, which varies from Andean cold to temperate, influencing the flora and fauna of the region; these temperate climate characteristics are utilized by the local inhabitants for the cultivation of products such as: sugarcane, corn, and cassava, among the most important.



2. GEOLOGY

2.1 Introduction

Details of the geological field observations, carried out mostly on foot, can be seen on the Tutupali-Río Ortega geological traverse map, which also includes at its bottom three small reconnaissance geological sections made in the Cantzama, Chicaña, and Chuchumbleza rivers (see single map); as in previous reports, it should be noted that all indicated data are provisional, based solely on macroscopic identifications of rock samples, because at the moment thin sections are not available, nor are geochemical results.

2.1.1 Tres Lagunas batholith

This batholith, better known as the Tres Lagunas Suite (XgTL), was named as such thanks to field results carried out by the South brigade (Aspden, Viteri, 1987) of the Cordillera Real Geological Research Project, a location where many outcrops of deformed biotite granite were found. Based on field observations previously made during the Cochapata-Yacuambí traverse, Aspden (1988), who reported the existence of XgTL boulders in the Yacuchingari and Tutupali rivers, saw the need to conduct a check in these sectors to establish the type of contact between the XgTL and the Loja division (DL) and its southern extension.

Following the Río Yacuchingari and a bridle path approximately parallel to the drainage, the eastern position of the XgTL can be located; unfortunately, the exact contact was not determined because the exposures are highly weathered, but it could be an intrusive contact due to the characteristics presented by the area.

Toward the south at the Río Santa Cleotilde, a field check was likewise carried out along a bridle path parallel to this river, finding better outcrops of both the DL and the XgTL, with the contact between these two components being intrusive in these sectors.

Lithologically, in the observed outcrops of the XgTL, it consists of a biotite granite with a granular, generally gneissic texture, where greyish-blue potassium feldspar megacrysts can be observed giving the shape of “eyes”; it also contains blue quartz, which could be associated with microshearing that is especially developed within the quartz grains.

In the contact zones between XgTL and the DL, the XgTL appears without deformation, except for some boulders from a small creek tributary of the Río Yacuchingari (CRFV-761).

There are XgTL boulders in the Río Ortega, which will be confirmed once thin sections are available, and in the Ortega Alto mines, blue quartz crystals could be seen as an effect of the weathering of some granite.



2.1.2 Loja division

In the surroundings of Tutupali, there is a domain of pelitic rocks which, in all observed exposures, present a strong cleavage; these rocks belong to the Loja division, specifically the best outcrops are located in the Yacuchingari, Santa Cleotilde, and Ortega Alto rivers, and on both banks of the Río Tutupali up to the town of Yacuambí.

These low-grade metamorphic rocks consist of a monotonous sequence of phyllites, graphitic phyllites, quartz phyllites, impure quartzites, and quartzites; green phyllites and metavolcanics have also been included within the DL.

This division is an important element within the regional geological context of the Cordillera Real in the south of the country.

It has not yet been possible to date the age of these rocks, which is why at the moment we are assuming a Lower Palaeozoic age, though this is not well confirmed.

Near the XgTL and along the western margin of the DL, structural inclinations are moderate with cross-cordillera strikes; in the Tutupali-Ortega Alto traverse, the cleavage of these rocks is penetrative S₂ and clearly visible. The lack of excellent exposures, the vegetation cover, and the inaccessibility in certain sectors make it difficult to have a clearer idea regarding a reliable structural interpretation for the DL, though possibly with detailed work, better results can be achieved.

Provisionally, it could be defined as an overthrust belt to the west and isoclinally folded to the east, this interpretation being consistent with results obtained in previous works.

In the Campana River, east of Yacuambí, very near the contact of this suite with the Zamora batholith, there is a sequence of hornfels and silicified rocks with significant disseminated sulphide mineralization (mainly pyrite); this would further confirm previous ideas that the Zamora batholith is intruding into the semipelitic rocks of the DL.

In conclusion, we could indicate that the semipelitic rocks of the DL have been intruded by the XgTL and by the Zamora batholith.

2.1.3 Zamora batholith

There are intrusive rocks of the Zamora Batholith east of Yacuambí, from the La Ilusión sector to Peñas Blancas (the place where the traverse ended). Additionally, blocks of intrusive rocks were observed in the Guando Grande, Paquintza, and Campana rivers. This batholith has not been mapped in detail, but according to the study of outcrops and boulders from the aforementioned rivers, it can be concluded that its composition varies from granodiorite with hornblende and biotite of medium grain to monzonite, quartz diorite, and diorite, with andesitic volcanic rocks and porphyries with disseminated sulphide mineralization.



2.2 Exotic blocks

This set of rocks known as exotic (Litherland et al., 1987) are important from an economic point of view and were located as boulders in the Espadillas and Campana Urco rivers.

2.2.1 Blocks of the exotic suite

According to research studies previously carried out on the Salado-Tena traverse (Litherland and Bermúdez, 1986), the rock complex existing in the Espadillas and Campana Urco rivers has a high degree of similarity.

- (a) In the Espadillas River, there are boulders of metavolcanics of greenish-grey colouring, aphanitic, of a basaltic composition, altered to epidote, with abundant content of disseminated sulphides; there are also blocks of chert and limestone.
- (b) In the Campana Urco River, there are boulders of black metavolcanics (which could be serpentinite) and a large number of large and small magnetite blocks.

The dark grey metavolcanics are found altered to epidote and present copper sulphide mineralization; these also contain magnetite in small and thin veinlets; there are also boulders of magnetite and ?skarn-type rocks, which will be confirmed with subsequent analyses; additionally, small blocks of chert could be seen.

It is interesting to mention that in the panned samples, the heavy mineral content includes garnet, magnetite, and gold among the most important.

The origin of this set of blocks should be to the east of the Espadillas and Campana Urco rivers, the location where the Manga Urco mountain range is situated, a sector that has not yet been explored.

3. GEOLOGICAL RECONNAISSANCE OF THE CHICAÑA, CHUCHUMBLEZA, AND CANTZAMA RIVERS

3.1 Introduction

The geological reconnaissance in the sectors of the Chicaña, Chuchumbleza, and Cantzama rivers had to be carried out with the objective of reviewing and having a clearer idea of the geology of these sectors located in the Subandean belt of the Cordillera Real; the results of the works carried out are indicated at the bottom of the geological map (see single map).

3.1.1 Río Cantzama

The objective of the visit to this river was to observe the existence or absence of basement rocks, especially as boulders of the Río Cantzama and its tributaries, in order to perform an interpretation on the project's 1:250000 scale base geological map.

As can be observed in the small geological section, lower left part of the map; at the junction of the Piuntza River with the Cantzama, there are good exposures of biotite granodiorite belonging to the Zamora batholith; this batholith is continuous until very near the junction of the Río Salado.

Subsequently, a meticulous examination of boulders from each of the rivers was carried out, resulting in the finding that in both the Río Cantzama and the Piuntza there are large blocks (up to 10 meters in diameter) of Sabanilla basement rocks.

Furthermore, the presence of silicified volcanic rocks with sulphides (pyrite, chalcopyrite) in the Piuntza and Cantzama rivers is important; as a result of panning in the Río Cantzama, gold specks could be seen, which would lead us to think of the existence of significant mineralized porphyritic volcanic rock bodies.

3.1.2 Río Chicaña

The objective was to observe the presence of foliated rocks on the road leading to the Chicaña River. From the San Vicente sector to the Chicaña River, following the road, the presence of granodiorite intrusive rocks could be seen, in some cases with hornblende and in others with biotite, with variations in their composition up to monzonites being observed; these rocks must belong to the Zamora Batholith. Additionally, volcanic rock veins (andesites?) could be seen within these intrusive rocks.

3.1.3 Río Chuchumbeza

The purpose was to perform a geological reconnaissance in this sector (see lower right part of the map), in which a predominance of silicified volcanic rocks, lavas, and tonalite outcrops could be observed.

Within the volcanic rocks, silicified agglomerates could be seen, in which copper minerals such as malachite, chalcopyrite, and pyrite were identified.

The extensive alluvial deposits located on both banks of the river are also important, where the gold mining company MINEROSA is established.

4. ECONOMIC GEOLOGY

4.1 Metallic minerals

4.1.1 Gold

Gold specks were observed in panned samples from various rivers and small creeks, tributaries that cut through both the Zamora Batholith and the XgTL.

It can be assumed that due to the abundance of sulphides in basic rock boulders and skarn-type rocks, they could contain interesting proportions of gold mineralization.

Among the main drainages containing alluvial gold, we have the Ortega, Campana Urco, Cambana, and Yacuchingari among the most important.



Currently, there are 17 miners at the Ortega Alto gold washings, which are located in a glacial deposition zone.

4.1.2 Copper/sulphides

Evidence of sulphides exists in volcanic rocks in the Cambana River near the contact with the intrusive rocks of the Zamora Batholith, where chalcopyrite/pyrite mineralization can be observed.

The ?skarn-type rocks of the Campana Urco River and the basic volcanics have a significant sulphide content of pyrite/chalcopyrite and bornite. There are blocks of epidotized lava containing chalcopyrite/pyrite mineralization with a lead-blue lustre.

4.1.3 Magnetite/Iron

Blocks of volcanic rocks in the Campana Urco River contain magnetite in thin veinlets (CR-FV-765C); likewise, massive magnetite boulders occur in the Espadillas and Campana Urco rivers.

4.2 Occurrences of non-metallic minerals

4.2.1 Silica

Significant outcrops of sandstones from the Hollín Formation contain large amounts of silica, especially on the left bank of the Río Chuchumbleza.

5. REFERENCIAS

LITHERLAND M. (1988) Proyecto Cordillera Real, Segundo Informe Anual, INEMIN-Misión Británica (no publicado).

LITHERLAND M. (1989) Proyecto Cordillera Real, Tercer Informe Anual, INEMIN-Misión Británica (no publicado).

VITERI F., SANTAMARÍA W. y SIERRA J. (1986) Hoja geológica Gualaquiza (en proceso), INEMIN.

Ing. Francisco Viteri S.
CORDILLERA REAL PROJECT

No. 00432

QUITO, JANUARY 17, 1990

TO : GERENTE TÉCNICO

FROM : DR. JOHN ASPDEN

SUBJECT : Technical Report of geological works carried out between Atillo-Macas (Río Abanico) and Alao-Huamboya-Palora from November 06 to December 02, 1989

1. INTRODUCTION

1.1 Project context

The geological research project of the Cordillera Real, which is carried out through a technical cooperation agreement between the governments of Ecuador and Great Britain, contemplates the collection of field data to understand the geology of the Cordillera Real, as well as its relationship with environments that control a possible mineral potential, for future local (detailed) works concerning the Instituto Ecuatoriano de Minería.

1.2 Objectives

The commission that is the subject of this technical report was carried out from November 06 to December 02, 1989; its objective was to perform the geological study of the Atillo-Macas (Río Abanico) and Alao-Huamboya-Palora crossings.

1.3 Assigned personnel

To carry out this work, the commission was composed of Dr. John Aspden, Mr. Manuel Céleri (who was unable to continue for health reasons), Mr. Laureano Saltos (who replaced Mr. Céleri), and Mr. Vicente Navarro (driver).

1.4 Transport

Jeep Land Rover, license plate AT-0272, from the British Mission.



1.5 Detailed activities

Month	Day	Traverse
November	06	Quito – Riobamba
	07-13	Atillo – Macas (mountain range crossing)
	14	Macas – Riobamba
	15	Riobamba
	16-30	Alao – Palora (mountain range crossing)
December	01	Palora – Baños – Alao
	02	Quito

1.6 Access

1.6.1 Atillo-Macas

There is a road to the west of Atillo via Guamote and, in dry weather, to Laguna Negra. In the east, the vehicle can enter the mountain range as far as Río El Retiro. Between these two points, a well-marked trail follows the course of the Río Upano. During our visit, all works on the projected Macas-Atillo-Guamote road were suspended.

1.6.2 Alao-Huamboya-Palora

From Alao, a now abandoned and impassable route crosses; the divide extends to Magdalena. From this point to El Placer, a rough trail exists. However, from this point forward, the trail has almost disappeared and access in many parts is possible only by machete. In the east, in the area of the Río Coco, small trails are used by miners who wash alluvial gold and reach the recent settlement of El Carmelo, which is approximately 14 km SW of Palora. Between Palora and El Carmelo, there is a drivable road.

1.7 Previous works

1.7.1 Atillo-Macas

Most of this traverse is covered by the Geological Map of Macas at a 1:100000 scale recently published (Marín et al., 1988). It will be noted, however, that there are considerable differences between that map and the present one. This work also covers the report of the first traverses by Litherland and Bermúdez (1986).

1.7.2 Alao-Huamboya-Palora

No publications are available regarding this traverse; however, a short section to El Placer was carried out by Litherland and Bermúdez in 1986.



2. GEOLOGY OF THE ATILLO-MACAS TRAVERSE

2.1 Alao-Paute division

Greenstones and greenschists belonging to the Alao-Paute division occur in the western part of the Atillo-Macas traverse. To the east of the Río Galgalán there are few outcrops of these rocks along the path, but numerous boulders are present.

Between Laguna Negra and the Río Galgalán the Alao-Paute division is well exposed and consists of an alternation of massive greenstones and strongly foliated greenschists. The greenschists are clearly of tectonic origin and represent mylonites produced along shear zones. Structural dips are generally moderate and mineral lineations have gentle dips with a north to NNE strike. Observations made in a single locality indicated dextral sense shearing.

Although the Alao-Paute division is dominated by metavolcanic rocks, minor amounts of black phyllites ± graphite were observed as boulders in some of the rivers that drain this sector. Also, in the Río Villacruz and in an unnamed river located a couple of kilometres to the east, mafic amphibolite boulders are present, very similar to the amphibolites of the Tampanchi Complex (see previous Project reports).

2.2 Loja division

In the Atillo-Macas sector the Loja division consists predominantly of semipelitic rocks, however, its metamorphic grade is variable. In the west (i.e. west of San Vicente), paragneisses and schists are common and garnet and chloritoid are widely developed. In the east, however, the metamorphic grade of the sequence is generally lower and typically consists of dark-coloured schists and phyllites, some of which are graphitic. In the San Francisco area the Loja division includes subordinate amounts of green schistose rocks of a possible volcanic origin.

The western margin of the Loja division is poorly defined due to the lack of outcrops, however, in the east it disappears abruptly through a “tectonic zone” which is marked in the field by the presence of a series of mylonitic rocks with strikes approximately N-S and with steep to vertical dips.

It is probable that the western boundary of the Loja division coincides with a reverse fault which has a moderate dip to the west. Schistose volcanic rocks that outcropped in a small unnamed stream within the Río El Retiro and Río Cugusha have a strong E-W mineral lineation and are believed to mark the beginning of the volcanic/volcanoclastic sequence that structurally serves as the base for the rocks of the Loja division.

Elsewhere in the mountain range and especially to the south, granites belonging to the Tres Lagunas suite (XgTL) are commonly associated with the Loja division into which they intrude. In the Atillo-Macas traverse outcrops of XgTL are not present, however, in the Río Playas and possibly in the Río Cugusha foliated biotite granite boulders that are tentatively assigned to the Tres Lagunas complex were observed.



Without a doubt, the Loja division is structurally complex. Dips and strikes are variable; in the west, NW-SE strikes seem to be dominant, but in the east, NE-SW strikes are more common. Immediately west of the Río El Retiro, mylonites are present with a westward dip and a strong E-W mineral lineation. These rocks mark a thrust fault, which is in all probability one of many occurring within this sequence.

2.3 Volcanic/volcanoclastic belt

The rock belt consists mainly of foliated volcanic rocks and volcanosedimentary rocks and may also include graywackes and small amounts of phyllites and impure quartzites.

Although this sequence is not particularly well exposed, mylonitic rocks, which mark shear zones on the surface, are common. Dips are generally to the west and north, with a north and northwest strike. In tectonic terms, this belt is structurally interpreted as underlying the Loja division, but due to the presence of a high-angle westward dip of a reverse fault, it lies over the Napo Formation in the Subandean zone.

At the western end of the belt, outcrops of foliated altered intrusives (immediately west of the Río Cugusha) are present.

2.4 Napo Formation

Outcrops of black phyllites present at the eastern end near the Río Colimbo are considered to belong to the Napo Formation. This assumption is not proven, but these rocks have a less complex structural history than those described previously and are still considered younger, i.e., Cretaceous in age.

Along the route leading to Macas, but west of the Río Abanico, the Napo Formation is extensively metamorphosed due to the presence of young intrusives.

2.5 Young rocks

2.5.1 Sedimentary rocks (Ts)

Immediately north of Laguna Atillo, a sequence of channel sandstone and immature siltstone rich in organic matter outcrops. These rocks have not been previously described, but they are assumed to be Tertiary in age. Regionally, they appear to be superimposed on the Alao-Paute division to the east and are likewise informally superimposed by young volcanics to the west.

These rocks are not metamorphosed and a single sample was collected, which contains well-preserved fish remains. This sample, along with another layer rich in organic matter, has been sent to the UK for paleontological determination.

2.5.2 Tertiary volcanics

In the west near Atillo, young volcanics (?Plio-Pleistocene) cover most of the area. It is assumed they belong to the Tarqui Formation.

Near Purshi and San Vicente, young lavas of predominantly andesitic and dacitic composition are present, possibly related to Sangay.

Outcrops mainly consisting of young felsic intrusives, dykes, were observed along the traverse, which are common near the margins of the Río Salado pluton.

2.5.3 Tertiary intrusives

The compositional range of the Río Salado pluton varies from diorite to granodiorite and probably includes minor amounts of leucogranite near its western margin. The intrusive, which contains hornblende and biotite, has not been dated, but it is assumed to be Tertiary in age. This assumption is based on the fact that the pluton is not deformed and contains xenoliths of the metamorphic basement. It also intrudes and affects by contact metamorphism the sediments believed to belong to the Napo Formation at the eastern end.

2.6 Economic Geology

2.6.1 Occurrences and economic potential of metallic minerals

2.6.1a Gold

Minor amounts of gold have been panned in the Río Playas, Río Salado Chico, and Río Alshi, but these resources probably have little economic potential.

According to the inhabitants of the small village of San Vicente, small amounts of gold have been taken from the Río Upano sector. Gold is also reported and worked in the Río Abanico, but the size of these operations is unknown.

2.6.1b Sulphides

Pyrite and possibly minor amounts of chalcopyrite are relatively common. The best indications are associated with small high-level intrusives and dykes of generally felsic composition, especially in the Subandean zone and along the western margin of the Salado pluton.

Pyrite is relatively common in the Alao-Paute division, but is of no economic interest.

To the east of Atillo, zones of pyritic alteration and minor amounts of sulphides were observed within the Tarqui Formation (see also 2.6.2a).

2.6.2 Occurrences and economic potential of non-metallic minerals

2.6.2a Sulphur

To the east of Atillo and associated with zones of pyritic alteration, minor amounts of native sulphur were observed within the Tarqui Formation.

The occurrence of sulphur and pyritic zones within the Tarqui Formation is of interest because these occurrences are located within the Altar-San Bartolome-Peggy regional polymetallic sulphide belt.



3. GEOLOGY OF THE ALAO-HUAMBOYA-PALORA TRAVERSE

3.1 Introduction

Good outcrops of more or less fresh rocks exist to the west of the traverse between the Quebrada Lilla and El Placer. However, to the east of El Placer, outcrops are very scarce and the geology (see Map 2) of this part is almost entirely represented by float blocks.

3.2 Alao-Paute division

The Alao-Paute division is exposed at the far west and consists mainly of greenschists and massive greenstones. It also includes minor amounts of metadolerites, outcrops of which were observed to the east of the bridge crossing the Río Alao along the road leading to Laguna Negra.

As is common in other parts of the mountain range, the development of schistosity within the Alao-Paute metavolcanics is mainly related to shear. The mineral lineation associated with these shearings is generally parallel to the strike (i.e. approx. N-S) and has a moderate plunge, frequently to the north. Structural dips are generally vertical to very steep.

3.3 Loja division

To the east of the Alao-Paute division, a narrow belt approximately 2 km wide was seen in the field, composed of quartz-schist rocks containing biotite $\pm$ chlorite $\pm$ feldspar. At the moment, these rocks are assigned to the Loja division, but for final confirmation we must wait for the results of thin-section analysis.

This belt has a N-S strike, with a moderate to very steep westward dip and is characterized by the presence of numerous sheared zones.

3.4 Tres Lagunas suite

Foliated plutonic rocks of the Tres Lagunas unit are exposed mainly to the west of Loma Magdalena and in other places, their presence is largely inferred by being present as numerous float blocks.

Basically, these rocks consist of medium to coarse-grained foliated granites and granodiorites containing biotite $\pm$ muscovite. Porphyritic varieties are common and the megacrystals normally consist of blue-grey orthoclase. Frequently, the quartz is pale blue.

The strike of the belt is consistent, more or less N-S, with vertical to very steep westward dips. The rocks, which are predominantly orthogneiss, are considered S-C type mylonites (Berthé et al., 1979) and result from non-coaxial deformation of major shear zones within the crust. However, more detailed studies are required to confirm the sense of movement of these shear zones.

3.5 Azafrán complex

The boundaries of this belt are poorly defined due to the almost complete lack of outcrops. However, as indicated on the traverse map, the Azafrán Complex is extensive and, as currently mapped, contains a variety of rock types; it is dominated by fine to medium-grained foliated plutonic rocks of granodioritic to dioritic composition. Hornblende and biotite are widely distributed. Granodiorites $\pm$ biotite are relatively common, being identical in hand sample to those of the Chingual metapluton, which is now considered the northern extension of the Azafrán Complex near the border with Colombia (Litherland, pers. comm.).

In the west, float blocks of paragneiss with garnet are common, and these have been included within the Azafrán Complex. However, it will be noted that although paragneiss xenoliths have been observed in float blocks of the Azafrán pluton, it is also possible that these rocks could be high-grade equivalents of the Loja division and therefore could be identical to similar rocks observed in the Atillo-Macas traverse (Río Abanico). It is of interest to note that euhedral garnets of up to 1-2 cm were collected from a block in the Río Collanes. Tourmaline contained in aplites and pegmatites is also present in the Río Cristal.

There is little structural information available on the Azafrán Complex; however, based on the few outcrops present, the foliation has an Andean strike with variable dips, but generally to the west.

3.6 Low-grade metasedimentary belt

At the eastern end of the traverse, at Loma Tiririco, a series of low-grade sedimentary rocks are exposed. These consist of poorly sorted tuffaceous sandstones and siltstones, probably also including dark-coloured phyllites.

A single outcrop of medium-grained, pyritic, and volcanic-rich immature greywacke was also seen in the Río Palora, upstream from the Río Bernardo.

These rocks have been grouped into a single unit, but at the moment their status is uncertain.

3.7 Young volcanics

In many rivers, float blocks of young volcanics of andesitic, dacitic, and felsic composition were observed. It is assumed that these rocks are probably Plio-Pleistocene in age and they are especially common in the east, i.e., downstream from the junction of the Río Encantado; they were obtained from a series of small intrusives (stocks and domes) which form the prominent morphology of this area.

3.8 Colluvial and alluvial deposits

In the east, large alluvial deposits and terraces are present; the main boundary is based on the interpretation of aerial photographs and is indicated on the attached traverse map.

Furthermore, east of El Placer, "narrow" colluvial and alluvial deposits are present in the Río Palora Valley; the boundaries are not indicated.



3.9 Economic Geology

3.9.1 Gold

Alluvial gold is common in the Río Palora, especially downstream from the Río Coco, and also in the Río Sangay.

According to the settlers, gold is also present in the Río Coco. Minor amounts were panned in the Río Collanes and reasonable samples (3-4 flakes/pan) were obtained from the Río Bernardo.

3.9.2 Polymetallic sulphides

Quartz veins (ca. 0.5-1 m wide) were observed near Laguna Negra and also to the west of Loma Magdalena carrying polymetallic sulphides. The following were identified in the field: galena, sphalerite, pyrite?, and chalcopyrite. A sample from the Magdalena vein has been sent for chemical analysis.

3.9.3 Sulphide mineralisation

Approximately 0.5 km east of the Río Lilla, a mineralized fault zone in the Alao-Paute division crosses the road leading to Laguna Negra. An old tunnel follows this zone to the north of the road for about 5 m. The zone contains disseminated sulphides, mainly pyrite, but no massive ore was observed.

This same zone continues south of the Río Alao, where oxidized sulphides can be seen and, according to our guides, they also crop out on the surface to the north.

3.9.4 Garnet and tourmaline

Garnets are common in the Cristal and Collanes rivers; especially in the Río Collanes, they are large (1-2 cm), euhedral, and dark red in colour.

Tourmalines are also present in the Río Cristal. These minerals are of mineralogical interest and not of economic value.

3.10 Mineral potential

3.10.1 Gold

Gold is worked in the lower part of the Sangay and Palora rivers. As indicated on the traverse map, terraces are present in this area and these could have potential for alluvial gold extraction.

Likewise, the upstream area, including the Río Coco, can be considered as having good potential for hard-rock gold mining.

The source of the gold is unknown; however, the abrupt increase in alluvial gold in the Río Palora around the Río Coco could suggest a probable source within the general area. Based on field observations, the increase in gold corresponds to an increase in float blocks of felsic and dacitic volcanics and subvolcanics that are inferred to form a series of prominent morphological ranges in this area.

It should be remembered that the Coco, Sangay, and Palora rivers are within the Sangay National Park.

3.10.2 Polymetallic sulphides

The occurrences of polymetallic sulphides near Laguna Negra and the mineralization associated with the shear zone of the Alao-Paute division are of regional interest, although on their own they likely hold little economic interest.

It is considered that this mineralization represents part of the Altar-San Bartolomé-Peggy regional polymetallic belt, referred to in the previous Project Annual Report. A regional geochemical study will likely be carried out over the entire belt to determine the economic potential of this area.

4. REFERENCES

D. BERTHÉ et al. (1979) Orthogneiss, mylonite and non-coaxial deformation of granites: the example of the South American Shear Zone. *Journal of Structural Geology*. Vol. 1, No. 1, pp. 31 to 42.

Dr. John Aspden
CORDILLERA REAL PROJECT



No. 01271

QUITO, MARCH 08, 1990

TO : GERENTE TÉCNICO

FROM : ING. RAMIRO BERMÚDEZ and DR. JOHN ASPDEN

SUBJECT : Technical Report of the commission carried out to the Provinces of Azuay, Morona Santiago and Chimborazo from January 23 to February 04, 1990.

SUMMARY:

The United Kingdom-INEMIN Technical Assistance Project, which studies the Cordillera Real, carried out this service commission in order to visit various points in the southern and southeastern zones of the country and correlate them within the geological-structural framework pre-established by the Project.

It should be emphasized that in the sectors presenting fault zones, the focus was on: determining the direction of movement of the faults in situ or taking oriented samples for study via microscopy (Peggy Mine, Sta. Teresita-La Punta, Baños, etc.).

The presence of Tampanchi-type rocks (blocks) near the Azul parish was confirmed, which had been reported by the Belgian Mission (verbal comm.).

Around 20 rock samples, 5 stream sediment samples, and 3 heavy sediment samples were collected for their respective study. No presence of gold (?) or relevant economic heavy minerals (?) was obtained during panning.

Originally, according to the itinerary presented in the respective request (No. 1658), it was not fully completed due to factors beyond the control of the commission members, such as: bad weather in the areas, rivers with increased flow, and lack of cooperation from people (Sangay National Park-Río Illushín, Osogochi, etc.).

1. INTRODUCTION

1.1 Objectives

Geological-structural study and sampling of rock, stream sediments, and heavy sediments. Special emphasis on preliminary studies of kinematic indicators.

1.2 Assigned personnel

The commission was composed of:

Ing. Ramiro Bermúdez (INEMIN)

Dr. John Aspden (ODA/BGS)

Sr. Víctor Vega (driver/INEMIN)

A Land Rover Jeep AT-0272 belonging to the Mission was used as transport.

1.3 Geographical aspects

The investigated areas are located to the south, southeast, and east-southeast of Quito; they respectively belong to Cuenca (Azuay), Sucúa (Macas), and Palora (Morona Santiago).

1.4 Climate and vegetation

Basically, the areas visited are in direct relation to the elevations as follows: from 2700 mamsl and 3500 mamsl (Sigsig-Principal-Azul, etc.), with a temperate Andean to cold Andean climate with temperatures fluctuating between 8 and 12 degrees Celsius approximately; and from 880 mamsl to 2500 mamsl (Macas, Baños, etc.) with a tropical to subtropical temperate climate. The vegetation is in close relationship with the climate; in the high zones, the vegetation is typical of the páramo: pajonales (tussock grass), chaparro (scrubland), with crops of potatoes, barley, etc.; and in the low zones, we have large crops of citrus, cane, etc., with tea plantations located in this area (Palora).

1.5 Hydrography

The main hydrographic axes in the visited areas are: Río Santa Bárbara, Río Pastaza, Río Illushín, Río Tutanangoza, El Ojal River, etc.

1.6 Previous works

Geological sheets 1:100000; Alausí (71) 1975, Riobamba (70) 1978, and Baños (88) 1980; sheets in which mapping of the metamorphic rocks of the Cordillera was carried out.

Additionally, information obtained by the Project in the first 3 years of research (First 1987, Second 1988, Third 1989, Annual Reports of the Cordillera Real Project) was fundamentally used).

1.7 Work methodology

1:50000 Census Sheets belonging to Huambi, Sucúa, Macas, Palora were used; as well as topographic sheets of Sigsig, Guachapala, etc. edited by the IGM and 1:60000 aerial photographs covering the area.

The work methodology was:

- Geological and structural observations “in situ”.
- Determination of the movement direction of fault zones.
- Collection of rock samples, heavy sediments, and stream sediments.



1.8 Geomorphology

The geomorphology of the visited areas is characterized by presenting zones with pronounced slopes and zones with gentle slopes.

1.9 Population

The inhabitants of the area, including the communities, are dedicated to agricultural, livestock, and grazing activities. The highest concentration of the population is located in Sigsig, Azul, Sucúa, Palora, etc.

1.10 Land use

In the area, a high percentage of the soil is dedicated to agricultural and livestock activities.

In certain areas, existing materials are used for the paving and maintenance of roads.

2. GEOLOGY

On the first day of the commission, several field checks were carried out in the area to the east of Cuenca:

2.1 Cuenca-Santa Ana-San Bartolomé road

Possible basement outcrops (Gualaceo and Sigsig, 1:50000 topographic sheets).

The Project has received unconfirmed reports of small mineralized (metamorphic) rock outcrops which have been located along the Cuenca-Sta. Ana road (Gualaceo sheet, coordinates: 7297-96752); we did not find metamorphic rock outcrops along this road, nor did we see rolled blocks of metamorphic rocks in the Río Quingeo (Gualaceo sheet, coordinates: 7297-96752).

2.2 “Tampanchi-type” rocks

Near El Azul (Guachapala, 1:50000 topographic sheet).

Near the El Azul parish (coordinates 752-9698). These rocks are very similar in hand samples to those occurring in the Tampanchi complex, located a few kilometres to the north (see 2nd Project Annual Report, 1987-1988, p. 12), but are frequently cut and sometimes brecciated by the presence of pink feldspars that have intergrowth crystals. Immediately before the El Azul stream and exposed by the road, there are outcrops of a tonalite taken as foliated biotite-diorite; the relationship of this rock and the hornblendites is unknown?

The El Azul rocks were discovered by the Belgian Mission, and according to Ing. Quevedo (verbal comm.), similar rocks are present as blocks to the east of the town of Shumir (Azogues, 1:50000 topographic sheet, 7479-96898).

2.3 Kinematic indicators

For preliminary studies of kinematic indicators along the Baños front (south of Sigsig), we spent half a day searching for macroscopic evidence along the road to the Peggy Mine. The high-water level of the Río Santa Bárbara prevented the study of “clean” outcrops of the deformed Tres Lagunas Batholith, exposed in the outcrops below the Peggy Mine along the banks of the Río Santa Bárbara; however, observations of mineral lineations at various points along the road suggested that the main movements in this sector of the Baños front were of the “dip-slip” type, having no major strike-slip component. In a single outcrop of mylonitic rock from the Alao-Paute division, very well-preserved rotated quartz “eyes” (porphyroclasts) with “tails” were observed; these structures indicated a dextral sense of movement with the Alao-Paute division overthrusting from the northwest to the southeast.

It must be emphasized that this work is preliminary and more detailed studies must be carried out in this sector and also for others in the Cordillera Real to properly understand the complex structural history of the Baños front.

2.4 Río Tutanangoza-Río Ojal

Background: this sector is located within the Sucúa geological sheet (in progress) 1:100000, Verset and Lascano.

2.5 Metamorphic rocks

2.5.1 Metavolcanic-volcanosedimentary assemblage.

This assemblage consists mainly of metavolcanic and metavolcanosedimentary rocks, and also includes minor amounts of metasedimentary rocks, as well as dark phyllites with more or less graphite and semipelitic rocks. At the moment we do not have thin sections of these rocks, but it appears that they belong to the greenschist facies.

To the east, the sequence is exposed approximately 3 km east of the Río Navembayme, but it is distant from the Cordillera Real due to a narrow-faulted package of the Hollín and Napo Formations. To the east of the Río Cunguentza Chico, outcrops are very scarce, although there are numerous blocks of metavolcanic/volcanosedimentary rocks and metasediments present in the terrace deposits occurring in this zone; the metamorphic grade and general appearance of these rocks is similar to those occurring to the east, for which reason we have included them in this sequence.

As can be seen in Map 1, the measurements of these rocks have some variation, but in general, the foliation follows the strike of the Cordillera and the dips are generally to the west, but vary from moderate to very steep.

To the east, mylonitic rocks are common and they have mineral lineations with the strike of the cordillera and moderate to gentle dips.



2.6 Hollín/Napo/Tena Formations

We do not have dating for these Formations, but they are identified lithologically.

Approximately half a kilometre east of the Río Cunguentza Chico and for 2 km along the Río Navembayme, pale quartzites belonging to the Hollin Fm. were observed; they are tectonically interstratified with black shales of the Napo Fm. In this last example, five repetitions of quartzites or sandstones of the Hollin Fm. can be seen, each 2-3 m wide and separated by a similar thickness of black shales of the Napo Fm.; this observation suggests a level of superficial overthrusting (“thin skinning”), which is probably present not only at the base of the Hollin Fm., but also within the Formation itself.

Additionally, to the Hollin and Napo Formations, some red and altered sandstones and red shales are present and common at the eastern end of the “traverse”. These rocks were not studied in detail, but we think they belong to the Tena Formation.

3. ECONOMIC GEOLOGY

3.1 Occurrences of metallic minerals

The results of the analysis of stream samples and heavy sediments are not included because they were sent for preparation; those results will be provided later.

3.1.1 Gold

The presence of gold was not observed during panning, nor were there signs of alteration in the rocks or in the rolled blocks.

According to the people in the area, alluvial gold is worked sporadically in the Río Tutanangoza (Sta. Teresita).

3.1.2 Pyrite

Crystallized pyrite (cubic) of half a centimetre is observed in the sediments of the Napo Formation.

3.2 Mineral potential

It is considered that the visited zones do not have major economic mineral potential.

3.2.1 Río Illushín

The presence of gold in the Río Illushín was verified, and during the summer season, more than twenty people normally work along the river (± 2 km upstream from the confluence with the Río Pastaza, verbal communication from local people).

Due to bad weather and the river being swollen, it was not possible to advance up the Río Iyuime, upstream.



3.2.2 Puyo-Baños road

Almost half a day was spent trying to locate kinematic indicators on the Baños road, in the Azafrán deformed plutonic complex. Many vertical and subvertical faults (fault zones) cut the Azafrán complex, which can be considered composed of Type-I S-C mylonite (Lister and Snoke, 1982); mineral lineations observed on the foliation surface generally have southward dips and vary from moderate to subhorizontal; this observation suggests that these rocks essentially formed an oblique regime of strike-slip faults which have a significant “dip-slip” component.

No clear macroscopic evidence was observed in the field for the sense of movement of these faults as dextral or sinistral, but oriented samples were collected for microscopic study.

4. REFERENCES

LISTER G. S. and SNOKE A. W. (1984) S.C mylonites. *Journal of Structural Geology*, Vol. 6, 617-638.

Ing. Ramiro Bermúdez

Dr. John A. Aspden

APPENDIX 2

Geochronology Programme

(Phase II) (2a-2c)

S. H. Harrison and C. C. Rundle

APPENDIX 2a

BRITISH GEOLOGICAL SURVEY

Overseas Directorate Visit Report Series

TECHNICAL REPORT WC/89/10/R

Report on a visit to Ecuador Geochronology sampling, Phase II

11 January – 30 March, 1989

Stephen M. Harrison

This report was prepared for ODA (Overseas Development Administration)

Bibliographic Reference

Harrison S. M. (1989) Report on a visit to Ecuador. Geochronology Sampling, Phase II. (Stalyn Paucar, Ed. 2026). *British Geological Survey Technical Report WC/89/10/R*.

Keyworth, Nottingham. British Geological Survey, 1989

1. DIARY OF EVENTS (1989)

January

- | | |
|-------|---|
| 11 | Flew from Heathrow to Miami. Stayed the night in Miami. |
| 12 | Flew from Miami to Quito, Ecuador. |
| 13 | Visited INEMIN offices, meeting project staff and discussing details of field and laboratory work. |
| 14-15 | Weekend. |
| 16 | Planned and prepared for fieldwork at INEMIN offices. |
| 17 | Drove from Quito to Tena, sampling garnetiferous gneisses at Papallacta and Misahuallí volcanic rocks near Archidona. Stayed the night in Tena. |
| 18 | Drove from Tena to Baños stopping to collect a large sample of the Azafrán granite for U-Pb zircon dating. From Baños intended to drive all the way to Cuenca but found the road was blocked at Cañar and were forced to stay the night in Alausí. |
| 19 | Drove from Alausí down to Machala to work in the El Oro Province. Stayed the night in Machala. |
| 20 | Drove from Machala to Las Balsas and Marcabelí in the central part of El Oro. Sampled the Marcabelí pluton. Drove back to Santa Rosa for the night. |
| 21 | Drove from Santa Rosa to Arenillas and sampled the amphibolite. Continued to La Bocana and sampled garnetiferous migmatitic gneisses of the Tahuín Group. Returned to Santa Rosa for the night. |
| 22 | Drove from Santa Rosa up to Loja. Stopped at Portovelo to collect amphibolite. Stayed the night in Loja. |
| 23 | From Loja drove to Valladolid. Collected a suite of meta-plutonic rocks and a suite of garnetiferous migmatitic gneisses from the Sabanilla metamorphic complex. Returned to Loja for the night. |
| 24 | Drove from Loja to Malacatos and collected a suite of rocks from one of the Tres Lagunas plutons exposed a few kilometres north of Malacatos. Returned to Loja. |
| 25 | Drove from Loja to Zamora. Collected samples of migmatitic orthogneiss from the Sabanilla complex. Continued on to Yantzaza and up the Río Chicaña valley to sample hornblende diorites thought to be part of the Zamora Batholith. Returned to Yantzaza for the night. |
-

26	Drove from Yantzaza to Saraguro via Zamora and Loja. Looked at more rocks of the Sabanilla complex but no rocks were collected. Stayed the night in Saraguro.
27	Hired two mules and two guides and trekked east from the main road north of Saraguro and reached a camp-site just west of Tres Lagunas.
28	Sampled the Tres Lagunas blue-quartz granite at its type locality. Stayed at the same camp-site for the night.
29	Packed up camp and trekked back to the main road. Returned to Saraguro for the night.
30	Drove from Saraguro to Cuenca. Spent the night in Cuenca. No samples collected.
31	From Cuenca drove to Peggy Mine and collected more samples of the Tres Lagunas suite. Returned to Cuenca for the night.

February	
01	Drove from Cuenca to Tampanchi sampling a hornblende gabbro that occurs within the Alao-Paute volcanic rocks. Then drove on to Riobamba for the night.
02	Drove from Riobamba to Quito ending the field trip.
03-28	Working in Quito at the INEMIN laboratories in Chillogallo preparing rock samples.

March	
01-05	Working in Quito at the INEMIN laboratories in Chillogallo preparing rock samples.
06-19	On leave.
20	Flew from Quito to Cuenca and then drove by Landrover to Paute and further east down the Río Paute valley to collect garnetiferous rocks from a mixed sequence of meta-sedimentary and meta-volcanic rocks. Returned to Cuenca for the night
21-27	On leave.
28	Visited INEMIN offices for final discussions with project staff.
29	Flew to U.K. via Miami.
30	Arrived in Gatwick at mid-day.

2. Introduction

This report details the work undertaken during the second phase of geochronological sampling in Ecuador between 12 January and 29 March 1989. The work is part of an ODA technical co-operation project between BGS and INEMIN (Instituto Ecuatoriano de Minería) on the geology of the Cordillera Real (BGS Overseas Division Project 14BJ).

The first phase of this geochronological sampling programme was carried out by Dr C.R. Rundle (Rundle, 1987a) in April and June of 1987. The samples collected during this period were primarily from the major plutons and were dated using Rb/Sr whole-rock and K/Ar mineral techniques (see Rundle, 1987b and Rundle, 1988 for the results of this analytical work).

The aim of the second phase of this programme was to collect samples firstly, from remaining plutons that had not been dated previously and secondly from garnetiferous metamorphic rocks. The plutonic rocks would be dated by a combination of Rb/Sr whole-rock and K/Ar mineral analysis, whereas the metamorphic rocks would be dated by Sm/Nd analysis on garnet - whole-rock pairs.

This work was carried out at the request of Drs. Litherland and Aspden (BGS staff on secondment in Ecuador) to support their geological field observations. As with the previous sampling programme the selection of rock units and possible sampling localities was made by these geologists. Having collected the samples, the rocks were crushed and sieved at the INEMIN laboratories, south Quito. The isotope work will be carried out at NERC Isotope Geology Centre (NIGC) in London.

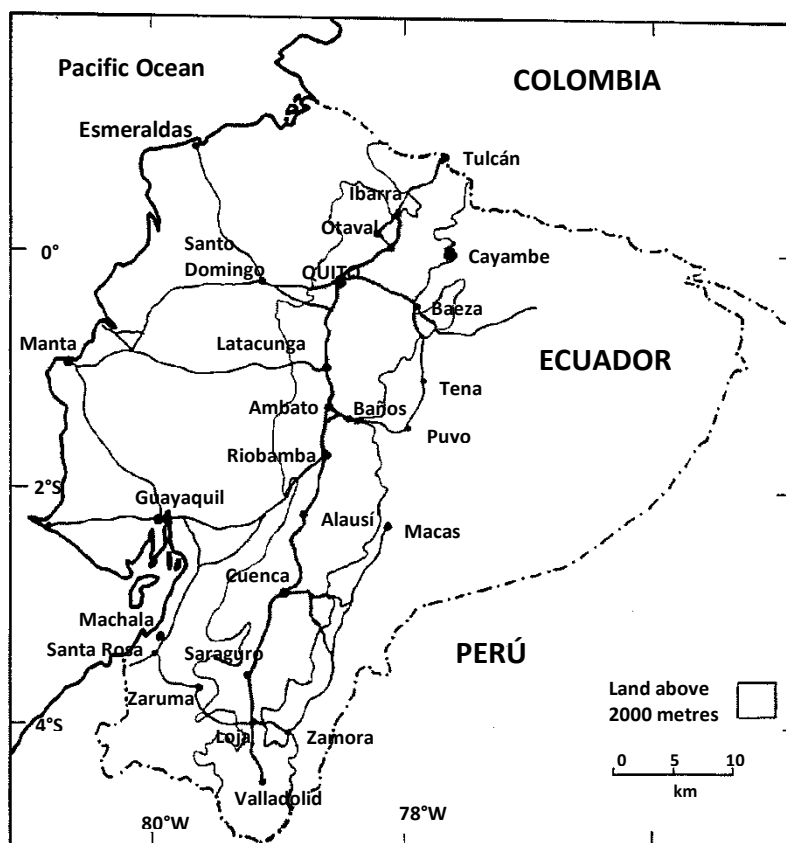


Figure 1. Sketch map of Ecuador showing principal towns and roads

3. Geological setting

The Ecuadorian Andes are less than 150 km wide and occur in the central part of Ecuador with the coastal lowlands (la Costa) to the west and the upper Amazonian rain forest (El Oriente) to the east. The Andes comprise two parallel ranges; the western Cordillera Occidental and the eastern Cordillera Real. In the central and northern parts of Ecuador these ranges are separated by the Inter-Andean Depression (Fig. 1).

The Cordillera Real Project is therefore primarily concerned with the geology of the eastern Ecuadorian Andes. A brief summary of the geology of this region is presented here based on the work of Drs. Litherland and Aspden (Litherland, 1988).

Two major fault zones, The Baños front and the Sub-Andean Front delineate three tectonic divisions; the Western, the Central and the Eastern belts (Fig. 2). The Western Belt comprises Late Mesozoic and Cenozoic sediments and lavas of which the most important unit is the Alao-Paute thought to represent part of an accreted island arc of Jurassic age. The Central Belt comprises migmatitic gneisses, various meta-sedimentary rocks of low metamorphic grade, a suite of predominantly deformed blue-quartz biotite granites with S-type characteristics (Tres Lagunas Suite) and typical I-type locally foliated hornblende-biotite granitoids of the Azafrán Batholith. The Eastern Belt is characterized by two more granitoid batholiths with I-type characteristics; the northern Abitagua and the southern Zamora batholiths. Other rock types within this belt include various sedimentary formations ranging in age from Late Palaeozoic to Cretaceous. Small undeformed plutons of hornblende-biotite granitoids occur in both the Central and Eastern belts.

Rundle (1987b; 1988) showed that the Abitagua and Zamora batholiths are Middle to Lower Jurassic in age. The Azafrán batholith yielded a Cretaceous age (120 ± 5 Ma) by the Rb/Sr whole-rock method, although one sample, thought to be part of the same intrusion, yielded concordant hornblende and biotite K/Ar mineral ages of 171 ± 5 and 176 ± 5 Ma respectively. Some of the undeformed plutons have yielded Tertiary ages. The age of the Tres Lagunas suite and the metamorphic rocks are unknown.

4. Fieldwork

The main part of the fieldwork was conducted over a single three-week period (17 Jan - 2 Feb 1989). One day of sampling was also carried out on 20 March. During the sampling the author was accompanied and guided by Dr. Aspden and his Ecuadorian counterpart geologist from INEMIN, Ing. Viteri S. Two drivers were supplied by INEMIN and these men were also responsible for the rock drilling and dynamite blasting. Two vehicles were used for the fieldwork; an ODA Landrover and an INEMIN pick-up truck.

Virtually all the localities visited were either road sections or at the banks of streams and rivers, which either crossed or were adjacent to roads. Although some localities away from the roads may have been better sampling sites, such trips are time consuming and logistically difficult to organize since it is necessary to hire guides and mules. In only one instance was such a trip made. At most localities it was necessary to use explosives to obtain fresh rocks due to the intense weathering but wherever possible sledge-hammers were also used.

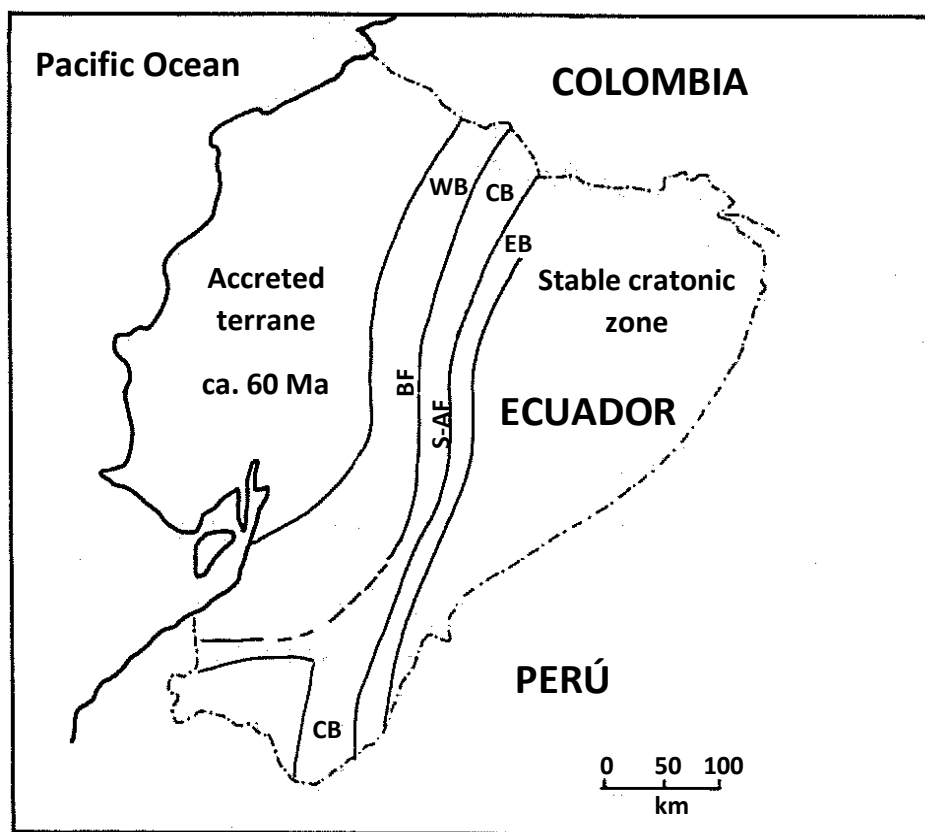


Figure 2. Provisional lithological/tectonic divisions of the Cordillera Real, Ecuador and their possible south-west extension into the El Oro Province based on Litherland (1988).

WB – Western Belt; **CB** – Central Belt; **EB** – Eastern Belt

BF – Baños Front; **S-AF** – Sub-Andean Belt

84 samples were collected during the three-week field trip and a further five samples were collected on the 20 March. Another 10 samples, previously collected by Dr. Aspden and Ing. Viteri S. were also added to the collection, making a total of 99 samples for radiometric dating.

5. Rock preparation

At the end of the fieldwork all the samples were taken to the INEMIN laboratories at Chillogallo for crushing and, where mineral separation was necessary, for sieving. The samples were wire-brushed clean prior to being broken up into small pieces using a hammer and anvil. The pieces were then jaw-crushed and roller-milled to granule-size. Samples for Rb-Sr whole-rock analysis, were powdered in a tungsten carbide swing mill using representative 200 g portions removed by passing the granules through a rifle splitter.

Samples requiring mineral separation were crushed as finally as possible using the roller-mill and were then sieved taking fractions between mesh sizes 65 and 200 (74 - 200 μm) for mineral separation.

Originally it was planned that the mineral separation would also take place in Ecuador using a super-panner. However, this was not in operation during the author's visit and all the mineral separation will now be carried out in the U.K.

The 200 g powdered samples for Rb-Sr whole-rock analysis were sent back to the U.K. via the diplomatic bag but the much larger sieved fractions for mineral separation were sent back by air-freight. All samples arrived safely in the U.K.

6. Summary

The sampling programme was very successful with all requirements met. Crushing and sieving of the samples at the INEMIN laboratories was also successful. However, no mineral separation was carried out due to the super-panner being out of operation and this will now have to be done back in the U.K.

A list of the collected samples (Table 1) and the appropriate dating techniques for each of them (Table 2) is presented.

Acknowledgements

I wish to thank John Aspden and Francisco Viteri for organizing the field trip and guiding me through the geology of much of Ecuador. The work of the INEMIN drivers (Manuel and Bolívar) in not only managing the vehicles but also in the safe handling of the rock drill and dynamite was much appreciated. The rock preparation at the INEMIN laboratories could not have been possible without the considerable help of the staff there and I am indebted to them.

Finally, I would like to thank Martin and Lilia Litherland and especially John and Gail Aspden for all the warm hospitality they have shown me during my visit in Ecuador.

References

LITHERLAND M. (1987) Cordillera Real Geological Research Project. First Annual Report. British Geological Survey.

LITHERLAND M. (1988) Cordillera Real Geological Research Project. Second Annual Report. British Geological Survey.

RUNDLE C. C. (1987a) Geochronology sampling in Ecuador, 1987. Report No. 87/12. British Geological Survey, Isotope Geology Unit.

RUNDLE C. C. (1987b) Rb-Sr analysis of rocks collected in May/June 1987 for the ODA-funded Cordillera Real Project, Ecuador. Report No. 87/1. NERC Scientific Services, Isotope Geology Centre.

RUNDLE (1988) Potassium-Argon ages for minerals from the Cordillera Real, Ecuador. Report No. 88/7. NERC Scientific Services, Isotope Geology Centre.

Table 1. List of samples collected for radiometric dating

CODE SAMPLE	SECTOR	COORDINATES	SHEET (1:500000)	COMMENTS
CR/SH/89-01A	Río Chalpi Grande	2470-5978	Papallacta	Garnet amphibolite
CR/SH/89-01B	Río Chalpi Grande	2470-5978	Papallacta	Banded biotite-garnet gneiss
CR/SH/89-01C	Río Chalpi Grande	2470-5978	Papallacta	Mafic gneiss with garnet and biotite
CR/SH/89-01D	Río Chalpi Grande	2470-5978	Papallacta	Biotite gneiss with garnet
CR/SH/89-02A	Archidona	8.5 km from Jondachi, Hollín-Loreto-Coca road	Sardinas	Felsic andesite
CR/SH/89-02B	Archidona	8.5 km from Jondachi, Hollín-Loreto-Coca road	Sardinas	Felsic andesite with hornblende
CR/SH/89-02C	Río Hollín Chico	8.5 km from Jondachi, Hollín-Loreto-Coca road	Sardinas	Andesitic tuffs with biotite and hornblende
CR/SH/89-02D	Río Hollín Grande	10.5 km from Jondachi, Hollín-Loreto-Coca road	Sardinas	Basaltic andesite with hornblende
CR/SH/89-03	Machay	8036-8449	Baños (census)	Azafrán Granite
CR/SH/89-04A	Cantera de balsas	3110-8468	Marcabellí	Monzonite? rich in biotite
CR/SH/89-04B	Cantera de balsas	3110-8468	Marcabellí	Monzonite? rich in biotite
CR/SH/89-04C	Cantera de balsas	3110-8468	Marcabellí	Monzonite? rich in biotite
CR/SH/89-04D	Cantera de balsas	3110-8468	Marcabellí	Monzonite? rich in biotite
CR/SH/89-04E	Cantera de balsas	3110-8468	Marcabellí	Monzonite? rich in biotite
CR/SH/89-04F	SE of Marcabellí Río Puyango	1882-7745	Marcabellí	Leucocratic granodiorite rich in biotite
CR/SH/89-04G	SE of Marcabellí Río Puyango	1882-7745	Marcabellí	Leucocratic granodiorite rich in biotite
CR/SH/89-04H	SE of Marcabellí Río Puyango	1882-7745	Marcabellí	Leucocratic granodiorite rich in biotite
CR/SH/89-04I	SE of Marcabellí Río Puyango	1882-7745	Marcabellí	Leucocratic granodiorite rich in biotite
CR/SH/89-04J	SE of Marcabellí Río Puyango	1882-7745	Marcabellí	Leucocratic granodiorite rich in biotite
CR/SH/89-05A	Arenillas	Arenillas	Arenillas	Amphibolite
CR/SH/89-05B	Arenillas	Arenillas	Arenillas	Amphibolite
CR/SH/89-06A	Sta. Teresita	ap. 9568-2128	La Avanzada	Migmatitic gneiss with garnet and biotite "La Bocana"
CR/SH/89-06B	Sta. Teresita	ap. 9568-2128	La Avanzada	Migmatitic gneiss with garnet and biotite "La Bocana"
CR/SH/89-06C	Sta. Teresita	ap. 9568-2128	La Avanzada	Migmatitic gneiss with garnet and biotite "La Bocana"
CR/SH/89-06D	Sta. Teresita	ap. 9568-2128	La Avanzada	Migmatitic gneiss with garnet and biotite "La Bocana"
CR/SH/89-06E	Sta. Teresita	ap. 9568-2128	La Avanzada	Migmatitic gneiss with garnet and biotite "La Bocana"
CR/SH/89-07A	Río El Negro	2185-9115	Marcabellí	Granodiorite? "La Bocana"
CR/SH/89-07B	Río El Negro	2185-9115	Marcabellí	Pegmatite with quartz, tourmaline, and muscovite
CR/SH/89-08A	Portovelo	Portovelo	Zaruma	Pegmatitic amphibolite
CR/SH/89-08B	Portovelo	Portovelo	Zaruma	Amphibolite
CR/SH/89-09A	near Q. Honda	0551-0632	Yangana	Migmatite
CR/SH/89-09B	near Q. Honda	0551-0632	Yangana	Migmatite
CR/SH/89-09C	near Q. Honda	0551-0632	Yangana	Migmatite
CR/SH/89-09D	near Q. Honda	0551-0632	Yangana	Migmatite
CR/SH/89-09E	near Q. Honda	0551-0632	Yangana	Migmatite
CR/SH/89-09F	near Q. Honda	0551-0632	Yangana	Migmatite
CR/SH/89-09G	Q. Honda	0495-0551	Yangana	Foliated plutonic rocks with biotite and quartz xenocrysts
CR/SH/89-09H	Q. Honda	0495-0551	Yangana	Foliated plutonic rocks with biotite and quartz xenocrysts
CR/SH/89-09I	Q. Honda	0495-0551	Yangana	Foliated plutonic rocks with biotite and quartz xenocrysts
CR/SH/89-09J	Río Valladolid	0761-9745	Valladolid	Migmatite with biotite and garnet
CR/SH/89-10A	Río Valladolid	0761-9745	Valladolid	Migmatite rich in biotite and with garnet
CR/SH/89-10B	Río Valladolid	0761-9745	Valladolid	Migmatite rich in biotite and with garnet
CR/SH/89-10C	Río Valladolid	0761-9745	Valladolid	Migmatite rich in biotite and with garnet
CR/SH/89-10D	Río Valladolid	0761-9745	Valladolid	Migmatite rich in biotite and with garnet
CR/SH/89-11A	Q. La Picota	9172-3940	Nambacola	
CR/SH/89-11B	Q. La Picota	9172-3940	Nambacola	
CR/SH/89-11C	Q. La Picota	9172-3940	Nambacola	
CR/SH/89-11D	Q. La Picota	9172-3940	Nambacola	
CR/SH/89-11E	Q. La Picota	9172-3940	Nambacola	
CR/SH/89-11F	Q. La Picota	9172-3940	Nambacola	
CR/SH/89-11G	Q. Cobalera	ap. 8948-3852	Gonzanamá	
CR/SH/89-11H	Q. Cobalera	ap. 8948-3852	Gonzanamá	
CR/SH/89-11I	Q. Cobalera	ap. 8948-3852	Gonzanamá	

Table 1. List of samples collected for radiometric dating (Continuation)

CODE SAMPLE	SECTOR	COORDINATES	SHEET (1:500000)	COMMENTS
CR/SH/89-12A	Sabanilla	1990-5870	Loja Norte	Sabanilla Migmatite - in some cases orthogneiss with foliated biotite - mafic orthogneiss rich in biotite
CR/SH/89-12B	Sabanilla	1990-5870	Loja Norte	
CR/SH/89-12C	Sabanilla	1990-5870	Loja Norte	
CR/SH/89-12D	Sabanilla	1970-6000	Loja Norte	
CR/SH/89-12E	Sabanilla	1970-6000	Loja Norte	
CR/SH/89-12F	Sabanilla	1970-6000	Loja Norte	
CR/SH/89-12G	Sabanilla	1970-6000	Loja Norte	
CR/SH/89-12H	Sabanilla	1970-6000	Loja Norte	
CR/SH/89-12I	Sabanilla	1970-6000	Loja Norte	
CR/SH/89-12J	Sabanilla	1970-6000	Loja Norte	
CR/SH/89-13A	Río Chicaña	4348-9269	Yantzaza	Pegmatitic hornblende diorite
CR/SH/89-13B	Río Chicaña	4348-9269	Yantzaza	Hornblende diorite
CR/SH/89-14A	Río Negro	1285-0522	Saraguro	
CR/SH/89-14B	Río Negro	1285-0522	Saraguro	
CR/SH/89-14C	Río Negro	1285-0522	Saraguro	
CR/SH/89-14D	Río Negro	1285-0522	Saraguro	
CR/SH/89-14E	Río Negro	1285-0522	Saraguro	
CR/SH/89-14F	Río Negro	1285-0522	Saraguro	
CR/SH/89-14G	Río Negro	1285-0522	Saraguro	
CR/SH/89-14H	Río Negro	1285-0522	Saraguro	
CR/SH/89-14I	Río Negro	1285-0522	Saraguro	
CR/SH/89-14J	Tres Lagunas	1315-0475	Saraguro	
CR/SH/89-14K	Tres Lagunas	1315-0475	Saraguro	
CR/SH/89-15	Río Pichanal	0445-9859	Saraguro	Biotite granodiorite
CR/SH/89-16A	Sigsig	4765-5768	Sigsig	"Tres Lagunas" suite: Gneissic granite with blue quartz
CR/SH/89-16B	Sigsig	4765-5768	Sigsig	"Tres Lagunas" suite: Gneissic granite with blue quartz
CR/SH/89-16C	Sigsig	4765-5768	Sigsig	"Tres Lagunas" suite: Gneissic granite with blue quartz
CR/SH/89-16D	Sigsig	4765-5768	Sigsig	"Tres Lagunas" suite: Gneissic granite with blue quartz
CR/SH/89-17A	Tampanchi	6188-0825	Cola de San Pablo	Hornblende gabbro
CR/SH/89-17B	Tampanchi	6188-0825	Cola de San Pablo	Hornblende pegmatite
CR/SH/89-17C	Tampanchi	6188-0825	Cola de San Pablo	Amphibolite
CR/SH/89-17D	Tampanchi	6188-0825	Cola de San Pablo	Hornblende pegmatite
CR/SH/89-18	Los Planes			Hornblende andesite
CR/SH/89-19	La Bocana		Marcabell	Pegmatite with muscovite and tourmaline
CR/SH/89-20A	Guarumales, Río Paute			Amphibolites
CR/SH/89-20B	Guarumales, Río Paute			Amphibolites
CR/SH/89-21A	Río Paute			Garnetiferous metasediments
CR/SH/89-21B	Río Paute			Garnetiferous metasediments
CR/SH/89-21C	Río Paute			Garnetiferous metasediments
CR/SH/89-22	Río Paute			Granodiorite
CR/SH/89-22	Río Paute			Granodiorite
CR/FV/664-D	Chuquiragua		Amaluza	Biotite granodiorite
CR/FV/681	Río Canela		La Canela	Biotite hornblende granodiorite
CR/FV/815	Portachuela		Laguna Cox	Porphyritic granite
CR/FV/819A	Portachuela		Laguna Cox	Porphyritic granite
CR/FV/819B	Portachuela		Laguna Cox	Porphyritic granite

Table 2. Summary of samples collected for geochronology programme listing the intended radiometric dating techniques to be used for each suite of rocks

All samples are prefixed by CR/SMH/89- except those from the last 4 localities, which are prefixed by CR/FV/-. Abbreviations: gt - garnet; hb - hornblende; bt - biotite; musc - muscovite; wr - whole-rock.

No. Sample	Quantity	Place	Method/Mineral
01 (A – D)	(4)	Garnet-bearing gneisses , Papallacta	10 Sm-Nd 5(gt + wr) y 1 K-Ar (hb)
02 (A – D)	(4)	Misahuallí volcanic rocks , Archidona	4 K-Ar (3hb y 1 wr)
03	(1)	Granodiorite , Azafrán quarry	U-Pb (circones)
04 (A – J)	(10)	Monzonite , Marcabellí.	10 Rb-Sr (wr) y 4 K-Ar (bt)
05 (A – B)	(2)	Amphibolite , Arenillas.	2 K-Ar (hb)
06 (A – E)	(5)	Garnet-bearing gneisses , near La Bocana.	10 Sm-Nd 5(gt + wr) y 5 K-Ar (bt)
07 (A – B)	(2)	Muscovite pegmatites , near La Bocana	3 K-Ar (2 mosc + 1 bt)
08 (A – B)	(2)	Amphibolites , Portovelo.	2 K-Ar (hb)
09 (A – J)	(10)	Metagranitoid , north of Valladolid.	10 Rb-Sr (wr)
10 (A – D)	(4)	Garnet-bearing gneisses , Valladolid.	8 Sm-Nd 4(gt + wr) y 4 K-Ar (bt)
11 (A – I)	(9)	Tres Lagunas granite , north of Malacatos.	9 Rb-Sr (wr) y 3 K-Ar (bt)
12 (A – J)	(10)	Sabanilla migmatite , Sabanilla.	10 Rb-Sr (wr) y 4 K-Ar (bt)
13 (A – B)	(2)	Hb diorites , Río Chicaña.	2 K-Ar (Hb)
14 (A – K)	(11)	Tres Lagunas granite , Tres Lagunas.	11 Rb-Sr (wr), 6 Sm-Nd 3(gt+wr) y 3 K-Ar (bt)
15	(1)	Granodiorite , north of Saraguro.	2 K-Ar (bt + hb)
16 (A – D)	(4)	Tres Lagunas granite , Peggy Mine.	4 Rb-Sr (wr)
17 (A – D)	(4)	Tampanchi complex (gabbro), Tampanchi.	3 K-Ar (2 hb + 1 wr)
18	(1)	Andesite , Los Planes.	1 K-Ar (hb)
19	(1)	Muscovite pegmatite , La Bocana.	1 K-Ar (mosc)
20 (A – B)	(2)	Amphibolites , Guarumales, Río Paute.	2 K-Ar (hb)
21 (A – C)	(3)	Garnet-bearing meta-sediments , Río Paute.	6 Sm-Nd 3(gt + wr)
22 (A – B)	(2)	Granodiorite , Río Paute.	4 K-Ar 2(hb + bt)
664 (D)	(1)	Granodiorite , Chuquiragua	2 K-Ar (hb + bt)
681	(1)	Granodiorite , Río La Canela	2 K-Ar (hb + bt)
815	(1)	Porphyry , Portachuela	1 K-Ar (bt)
819 (A – B)	(2)	Porphyry , Portachuela	2 K-Ar (bt)

TOTAL: 99 Samples	
5	Rb-Sr isochron suites (54 samples)
5	Sm-Nd isochron suites (20 gt+wr pairs)
32	K-Ar (bt)
20	K-Ar (hb)
3	K-Ar (mosc)
2	K-Ar (wr)
1	U-Pb (zircons)

APPENDIX 2b

BRITISH GEOLOGICAL SURVEY

Overseas Directorate Series

TECHNICAL REPORT WC/90/12

**Radiometric ages (Rb-Sr, K-Ar y Sm-Nd) for rocks from the
Cordillera Real, Ecuador:**

Phase II

by

Stephen M. Harrison

This report was prepared for the ODA (Overseas Development Administration)

Bibliographic reference

Harrison S. M. (1990) *Radiometric ages (Rb-Sr, K-Ar y Sm-Nd) for rocks from the Cordillera Real, Ecuador: Phase II* (Stalyn Paucar, Trad. y Ed., 2026). British Geological Survey Technical Report WC/90/12

Keyworth, Nottingham. British Geological Survey, 1989

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1. INTRODUCTION

This report details the analytical results of the second phase of the geochronology programme on rocks from the Cordillera Real, Ecuador as part of the BGS Overseas Division Project 14BJ. The first phase of this programme was carried out by Dr C.C. Rundle at the NERC Isotope Geology Centre and the results of this work are presented in Rundle (1987a; 1987b; 1988). The objective of this earlier work was to date the main granitoid intrusions of the Cordillera Real using Rb-Sr and K-Ar radiometric isotope techniques.

The second phase of the geochronology of the Cordillera Real project commenced in January 1989. The author was employed for a seven-month contract by the British Geological Survey with funding from the Overseas Development Administration. Seven weeks were spent in Ecuador collecting, crushing and sieving the samples and the remainder of the time carrying out the mineral separation and radiometric dating in the UK, based at the NERC Isotope Geology Centre. Details of the sample collection and preparation are presented in Harrison (1989).

The main objective of this second phase of geochronology was to attempt to date the main metamorphic units of the Cordillera Real, using a combination of Rb-Sr, K-Ar and Sm-Nd techniques.

2. ANALYTICAL DETAILS

2.1 Rb-Sr analysis

Rb-Sr analysis was carried out on whole-rock powder samples from meta-plutonic rocks and orthogneisses.

Rb/Sr ratios were analysed by X-ray fluorescence using an automated Philips spectrometer. Pressed powder pellets were made for this purpose. The analysis was carried out by the Analytical Chemistry section of the British Geological Survey at Grays Inn Road, London. For the strontium isotope determination, strontium was extracted from the samples using acid dissolution and ion exchange methods in a clean-chemistry laboratory. The strontium isotopes were then analysed on an automated multi-collector VG354 mass spectrometer.

The Rb/Sr ratios are quoted with a blanket error of $\pm 0.5\%$ (1-Sigma). Replicate analyses of samples and standards suggest that an error of $\pm 0.005\%$ is appropriate for the strontium isotope measurements.

Replicate analyses of international standards indicates that the results are accurate within the precision estimates.

The errors on age and initial ratio (R_i) are quoted as 2-sigma (95 % confidence level) and refer to the last significant figure. Best-fit lines on the isochron diagrams were calculated using a least-squares fitting programme. Where the calculated parameter MSWD (Mean Standard of Weighted Deviates) exceeds 3.0 it is inferred that the points do not all fit the line within the limits of analytical error and, following conventional practice, the errors on age and intercept are enhanced by multiplying by the square root of the MSWD. All ages are calculated using a decay constant for ^{87}Rb of 1.42×10^{-11} .

2.2 Sm-Nd analysis

This technique is used on multiple whole-rock and garnet pairs relying on the fractionation of the rare earth elements in garnet relative to the host whole-rock.

Sm and Nd are analysed by a double isotope dilution method. Powdered whole-rock and garnet samples are dissolved in acid with an added amount of a Sm-Nd mixed spike. Both the Sm and the Nd are then extracted using ion exchange methods and are separately analysed on the VG354 mass spectrometer. The Nd isotope determination is carried out automatically during the same run as the Nd concentration analysis.

Errors on the Sm/Nd and the $^{143}/^{144}\text{Nd}$ analyses are quoted as 0.2 % and 0.005 % (1-sigma) respectively, again based on replicate international standards. The results are presented in the form of isochron diagrams similar to Rb-Sr and the techniques used in calculating the best-fit lines, ages and errors are the same.

2.3 K-Ar analysis

K-Ar analysis was carried out predominantly on biotite, muscovite, and hornblende separates and only rarely on whole-rock samples. This technique was used on virtually all suites collected where the appropriate unaltered minerals were present to support either the Rb-Sr or the Sm-Nd results.

The potassium was determined, at least in duplicate, using an Instrumentation Laboratories IL543 flame photometer with lithium as internal standard. The argon was extracted by fusion under vacuum using external Radio-frequency Induction heating and analysed by the isotope dilution method in a VG Isotopes MM1200 mass spectrometer.

Replicate determinations of in-house standards suggest that an overall precision of ± 1 % (1-sigma) is realistic for the potassium analyses. The error on the radiogenic argon determination is partly dependent on the amount of contaminating atmospheric argon, which often reflects the degree of deuteritic alteration and hence varies considerably between samples. The argon spike system was calibrated against international standards and so the results can be expected to be accurate within the limits of analytical error. The ages were calculated using the constants recommended by Steiger and Jaeger (1977) and the error on the age is quoted at the 95 % confidence level.

3. RESULTS

A list of the samples collected is presented in Table 1. The Rb-Sr and Sm-Nd analyses are presented in Tables 2 and 3 respectively with the isochron diagrams shown in Figs. 1 - 8. The K-Ar analyses and the calculated ages are presented in Table 4. Results from each of the suites collected are described and discussed below.

- **CR/SH/89 – 01 (A – D)**

Migmatitic garnet gneisses, Papallacta (7 km east of Papallacta in river bed).

All the samples are pelitic garnet biotite gneisses with graphite and small amounts of muscovite with the exception of 1A, which is a garnet amphibolite.

Sm-Nd data (Fig. 1): the garnet from these rocks shows little, and in some cases no fractionation of the Sm/Nd ratio. Hence it is not possible to obtain a reliable age from this data. The garnet amphibolite (01-A) has higher $^{143}\text{Nd}/^{144}\text{Nd}$ and Sm/Nd ratios but the line joining this sample with the other samples as shown is more likely to be a mixing line rather than an indication of the age.

K-Ar data (Table 4): the apparent ages obtained vary from Precambrian to Tertiary. To make any sense of this data it would be necessary to analyse more samples from this locality. The most likely situation is that the K-Ar systematics have been altered leading to, in some cases, local enrichment of radiogenic argon and hence old ages. At this stage these ages should not be interpreted as “true” ages.

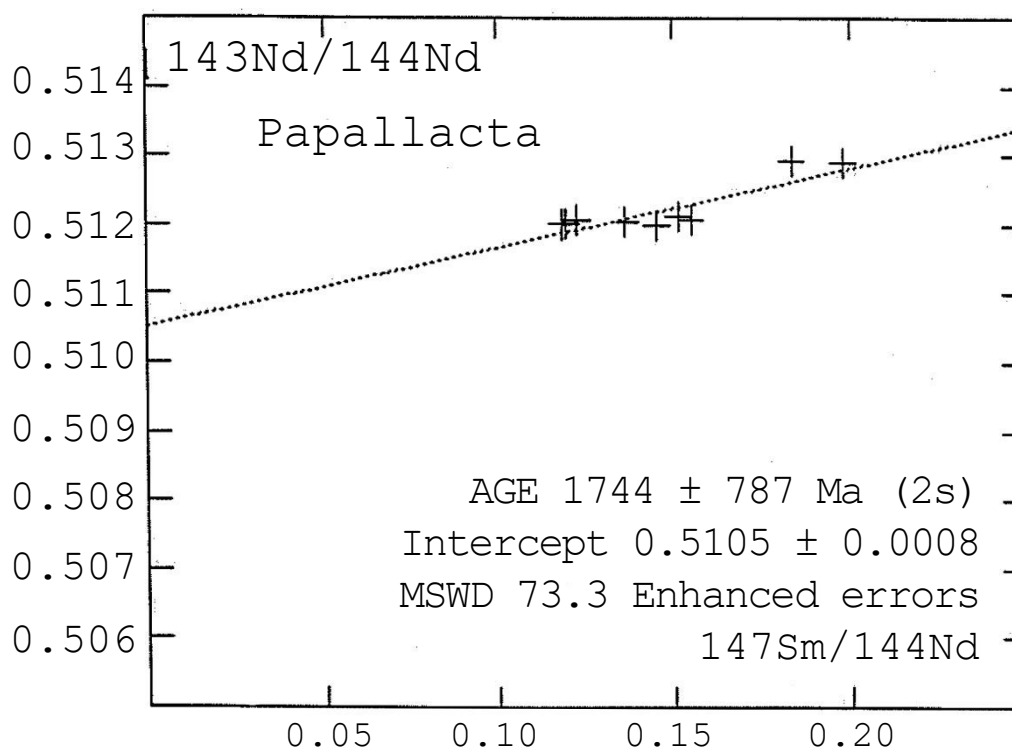


Figure 1. Sm-Nd isochron diagram for the garnet gneisses of Papallacta (CR/SH/89-01 A - E). No age can be obtained from this data

- **CR/SH/89 – 02 (A – D)**

Andesitic lavas (A - C) and an olivine basalt (D), Archidona.

The andesites are part of the Misahuallí Formation but the olivine basalt is likely to be post-Cretaceous in age.

None of these samples have been analysed since it was not possible to extract any hornblende from the andesite samples and the olivine basalt was thought not to be important to this study.

- **CR/SH/89 – 03**

Granodiorite, Azafrán quarry.

This sample was collected for U-Pb zircon analysis.

It has not been possible to do this work since there has neither been the time to separate the zircons nor the facilities at NIGC to carry out the analysis.

- **CR/SH/89 – 04 (A – J)**

Monzonite, Marcabellí, El Oro Province.

Samples 04 A - E were collected from a quarry 1 km south of Las Balsas and the other five samples were collected from approximately 10 km west, where the road meets the Río Puyango. No outcrops were seen between these two localities but it was thought quite likely that they represented the same intrusion.

Rb-Sr data (Fig. 2): the data form a scatter on the isochron diagram and no age can be obtained. Plotting the data from the two localities separately makes little difference. Clearly the Sr isotope systematics in these rocks are not in equilibrium.

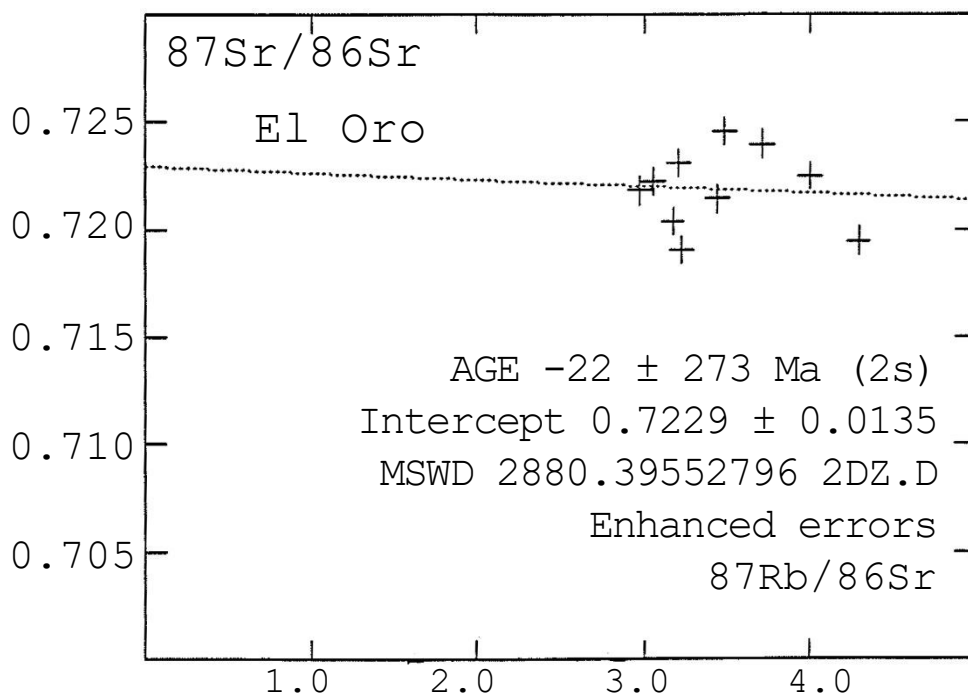


Figure 2. Rb-Sr isochron diagram for the Marcabellí pluton, El Oro (CR/SH/89-04A-J)

K-Ar data (Table 4): the ages from biotite and muscovite samples from 04A and 04H vary from 221 to 193 Ma and all are almost within error of each other. Without good Rb-Sr data it is not possible to say for certain whether the dates represent reset metamorphic ages or original crystallization ages. All the rocks appear undeformed, which would suggest the latter but biotite and muscovite K-Ar ages from metamorphic rocks, also in the El Oro Province (06 and 07), indicate a metamorphic event at this time.

- **CR/SH/89 – 05 (A – B)**

Amphibolites, Arenillas, El Oro Province.

These rocks are from the Piedras Group and Kennerley (1980) had obtained an age of 743 ± 14 Ma from an amphibole separate with very low K content (0.084 %). It was hoped that this age could be confirmed from the rocks collected in this study.

K-Ar data (Table 4): both hornblende separates with typical K contents (0.36 %) yielded ages of approximately 70 Ma. These are almost certainly reset ages and cannot discount the Precambrian age of Kennerley (1980).

- **CR/SH/89 – 06 (A – E)**

Pelitic garnet biotite muscovite gneisses with graphite, Santa Teresita near La Bocana, El Oro Province. These samples are from the Tahuín Group.

Sm-Nd data (Fig. 3): the data from 06 samples are combined with sample 19 (see below) and together form a well-defined isochron indicating an age of 217 ± 24 Ma for the growth of the garnet. This age corresponds very well with the K-Ar data, which is clear evidence that this is the age of an important metamorphic event.

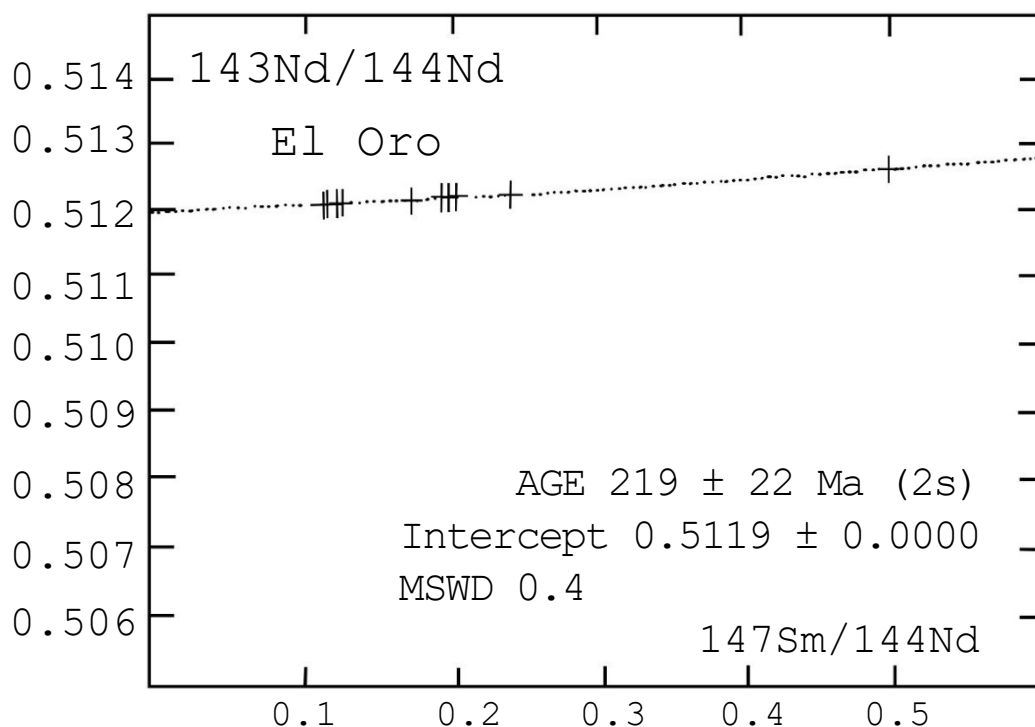


Figure 3. Sm-Nd isochron diagram of the garnet gneisses from El Oro (CR/SH/89- 06 A - E and CR/SH/89- 19)

K-Ar data (Table 4): the biotite and muscovite ages from the samples 06-B, -C, -D are all within error of each other and vary from 213 and 207 Ma. The close correspondence with the age of the garnet growth indicates that these ages represent the metamorphic crystallization of these minerals.

- **CR/SH/89 – 07 (A – B)**

Felsic pegmatites, Río Negro near La Bocana, El Oro Province.

These samples are also part of the Tahuín Group and are closely associated with the samples from 06 above. It was not possible to extract either biotite or muscovite from 07-B.

K-Ar data (Table 4): the ages from the biotite and muscovite from 07-A (216 and 220 Ma respectively) are slightly older than those from the 06 samples but are still in close agreement.

- **CR/SH/89 – 08 (A – B)**

Amphibolites, Portovelo.

These amphibolites could be related to those at Arenillas and again it was hoped to confirm or disprove a Precambrian age.

K-Ar data (Table 4): both the amphiboles extracted from these samples have very low K content (0.07 and 0.05) but yield very different ages (224 and 647 Ma) even though they are from the same outcrop. The 224 Ma age may be representing the metamorphic event defined in 06 and 07 but the 647 Ma age cannot be relied upon and, as with the 01 samples, 07-B has probably suffered argon enrichment.

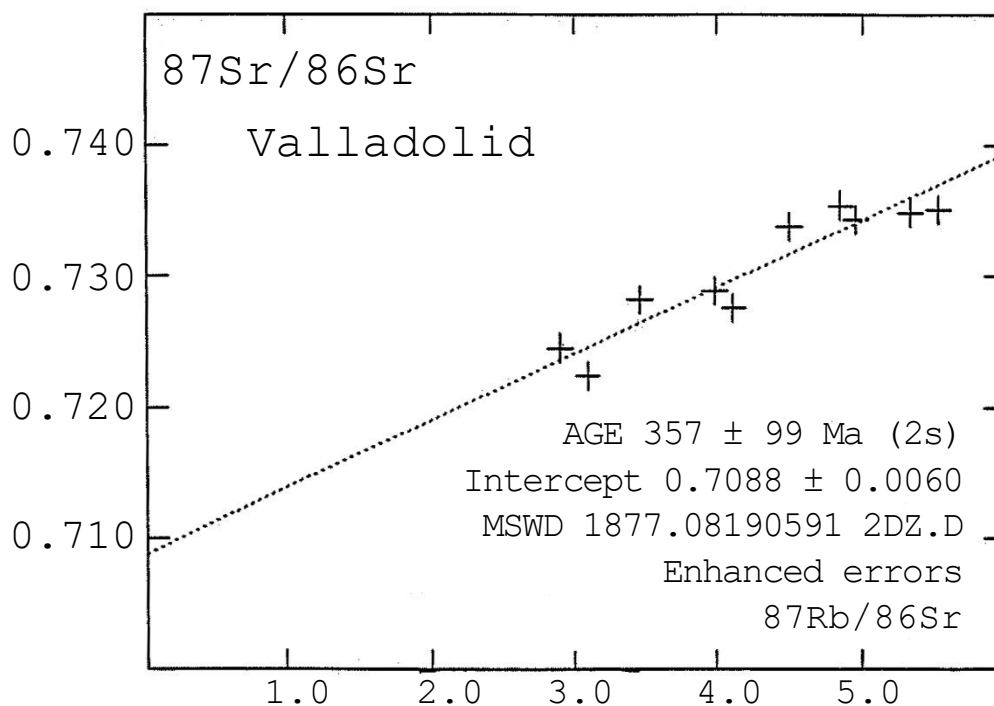


Figure 4. Rb-Sr isochron diagram for the meta-granitoid suite of samples that outcrop on the road section near the top of the pass between Loja and Valladolid (CR/SH/89-09A - J)

- **CR/SH/89 – 09 (A – J)**

Metagranitoid, top of pass between Loja and Valladolid.

This intrusion is adjacent to high grade metamorphic rocks (similar to those of 10) but the contacts are not exposed. However, the rocks show signs of weathering and were only analysed for Rb-Sr.

Rb-Sr data (Fig. 4): the combined data define a poor errorchron of 357 ± 99 Ma with a very high MSWD of 1877. Although the age is poorly constrained the linear array, which the data define, suggests that the age may be meaningful.

- **CR/SH/89 – 10 (A – D)**

Migmatitic garnet biotite muscovite gneisses with graphite, Valladolid.

Sm-Nd data: the garnet from these rocks, as with those from Papallacta, has not fractionated the Sm/Nd ratio and hence it is not possible to obtain an age from these rocks by this method.

K-Ar data (Table 4): the ages obtained from the muscovite and biotite from these rocks vary from 85 to 69 Ma. These are likely to be reset ages.

- **CR/SH/89 – 11 (A – I)**

2-mica meta-granitoid of the Tres Lagunas suite, Malacatos.

Rb-Sr data (Fig. 5): the combined data yields a poor errorchron of 116 ± 40 with an MSWD of 136. However, the sample 11-G plots well away from the rest of the samples and omitting this point the age increases to 194 ± 50 with a much lower MSWD of 49.5. The high error on the age is due to the restricted variation of the Rb/Sr ratio. The 194 Ma age would appear to be the more realistic but as yet there is no geological reason for omitting this sample. A detailed petrographic analysis may resolve the problem.

K-Ar data (Table 4): the muscovite separates give very consistent ages of about 99 Ma whereas the biotite separates from the same rock yield ages of approximately 64 Ma. The biotites are clearly reset and it appears that the muscovites are also reset but at earlier stage being unaffected by the 64 Ma event.

- **CR/SH/89 – 12 (A – J)**

Orthogneiss suite of the Sabanilla metamorphic complex, Sabanilla.

This orthogneiss was analysed by Rundle (1987b) and he had obtained an age of 233 ± 51 Ma (MSWD = 175) from a suite of rocks collected along a 2 km section. In an attempt to reduce the errors on this age another suite of samples was collected from just one outcrop of less than 10 m².

Rb-Sr data: the set of samples analysed here define an errorchron giving an age of 198 ± 45 Ma (MSWD = 25.3) (Fig. 6a), which is a slightly better constrained age than previously obtained. When the two datasets are combined together (Fig. 6b), an age of 224 ± 37 Ma with an MSWD of 108. Although there are still large errors involved this seems to be a realistic age but it is not known whether this represents a metamorphic age (it corresponds well with the metamorphic event above) or an original intrusive age.

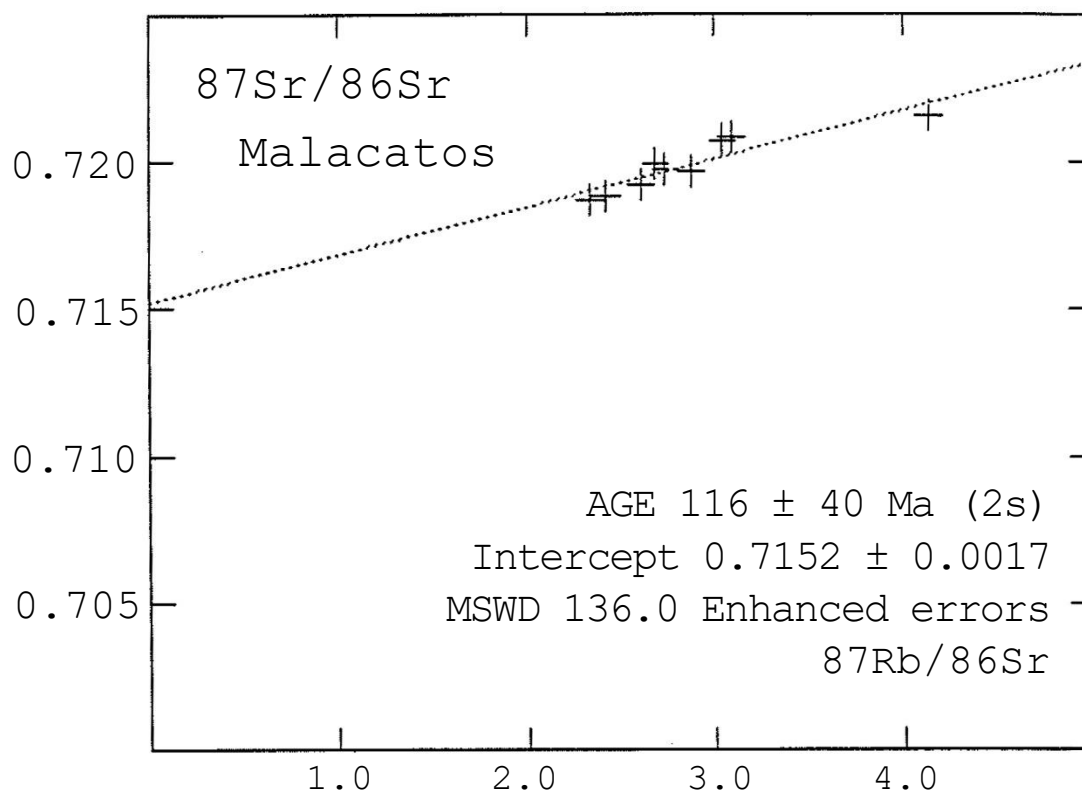


Figure 5a. Rb-Sr isochron diagram for the Tres Lagunas granite exposed north of Malacatos (CR/SH/89- 11 A - I)

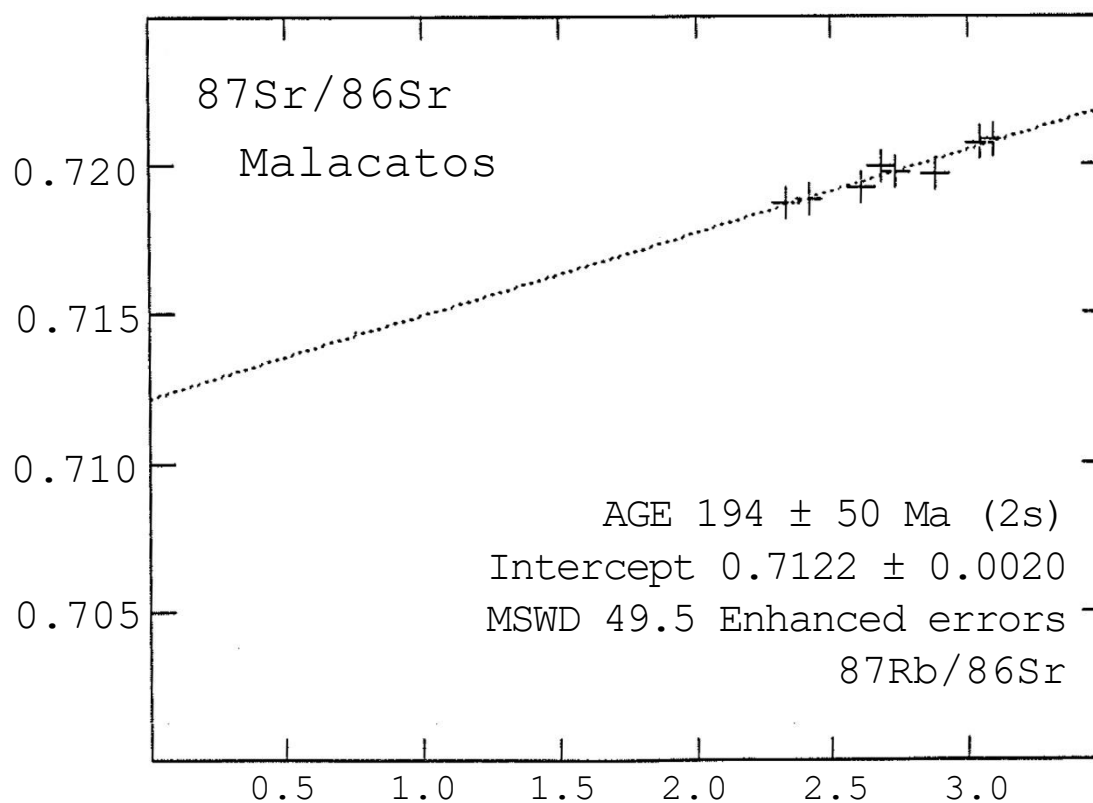


Figure 5b. As for Fig. 5(a) but without sample 11-G

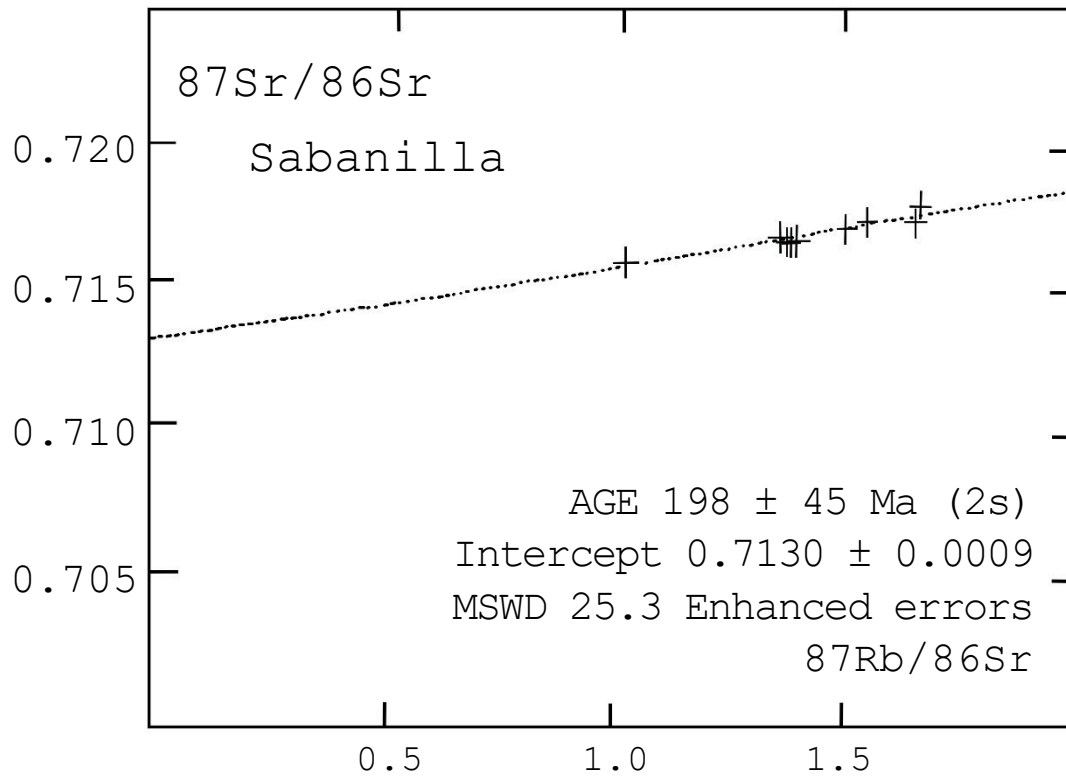


Figure 6a. Rb-Sr isochron diagram for the orthogneiss at Sabanilla (CR/SH/89-12A - J)

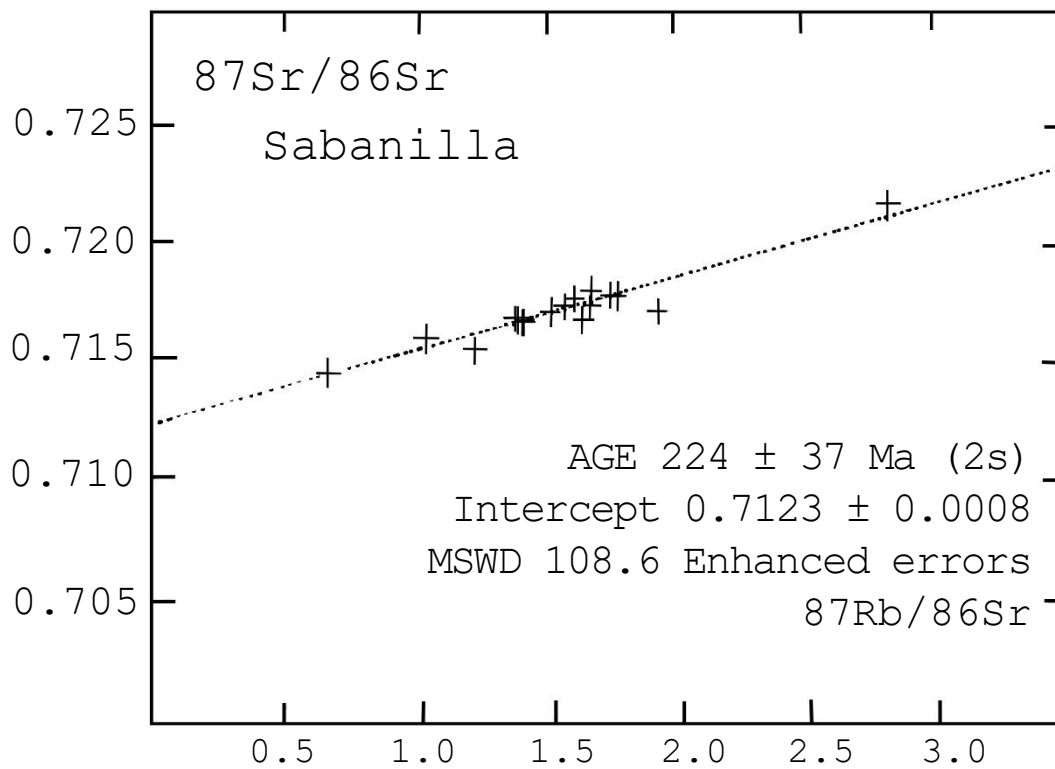


Figure 6b. As for Fig. 6(a) but with the data (E/87/23A - H) from Rundle (1987b) added

K-Ar data (Table 4): the muscovites yield ages of 65 Ma and the biotites give ages of about 85 Ma. Both of these ages are representing reset events. It is unusual to have muscovites giving younger ages than co-existing biotites but the muscovite in this case does not appear to be particularly fresh.

- **CR/SH/89 – 13 (A – B)**

Hornblende diorites, Río Chicaña.

These two samples were collected north of Zamora and are probably part of the Zamora batholith.

K-Ar data (Table 4): both hornblendes give ages of about 190 Ma and this is consistent with the oldest ages from the Zamora batholith (Rundle, 1987b; 1988).

- **CR/SH/89 – 14 (A – K)**

Tres Lagunas granite, Tres Lagunas.

Rb-Sr data: when all the samples are plotted together a poorly constrained age of 156 ± 40 with an MSWD of 457 is obtained (Fig. 7a). Sample 11-F was noted in the field as having alteration veins running through it and if this sample is removed the error is reduced and the MSWD is halved (289) and an age of 189 ± 43 Ma is obtained (Fig. 7b). This is still an errorchron but interestingly this age is very similar to that of the Tres Lagunas granite at Malacatos (194 ± 50 Ma) and they both have very similar initial ratios (0.7122 and 0.7129). In Fig. 7c the two data sets are combined and a considerably better constrained age of 200 ± 12 Ma (MSWD = 169) is achieved with an $R_i = 0.7120$. This strongly suggests that the two suites are petrogenetically related.

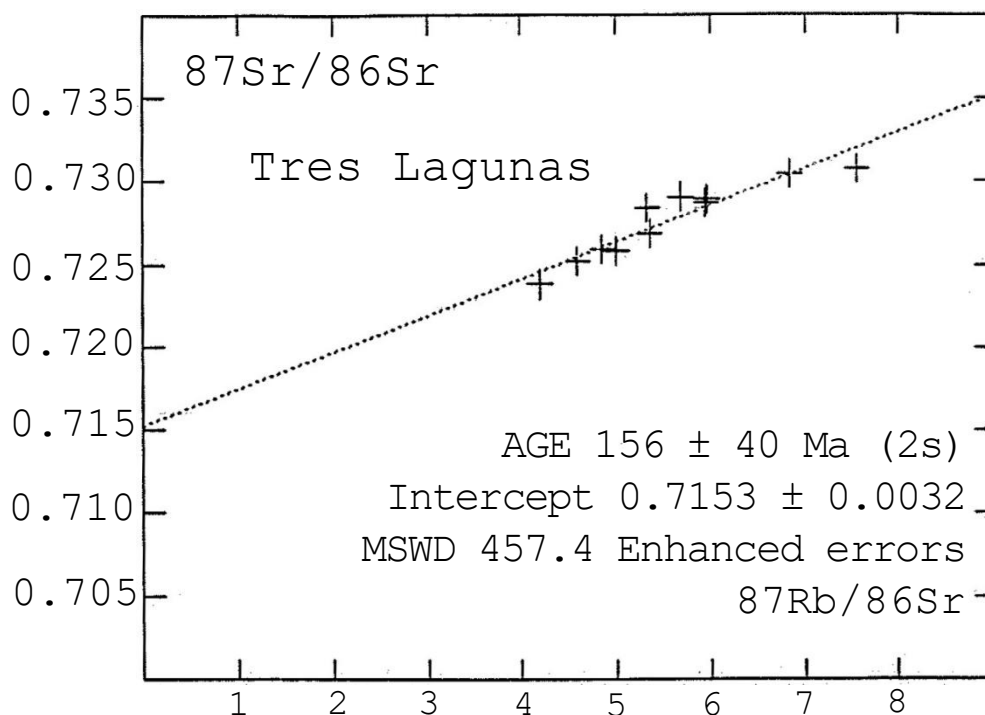


Figure 7a. Rb-Sr isochron diagram for the Tres Lagunas granite exposed at Tres Lagunas (CR/SH/89-14A - K)

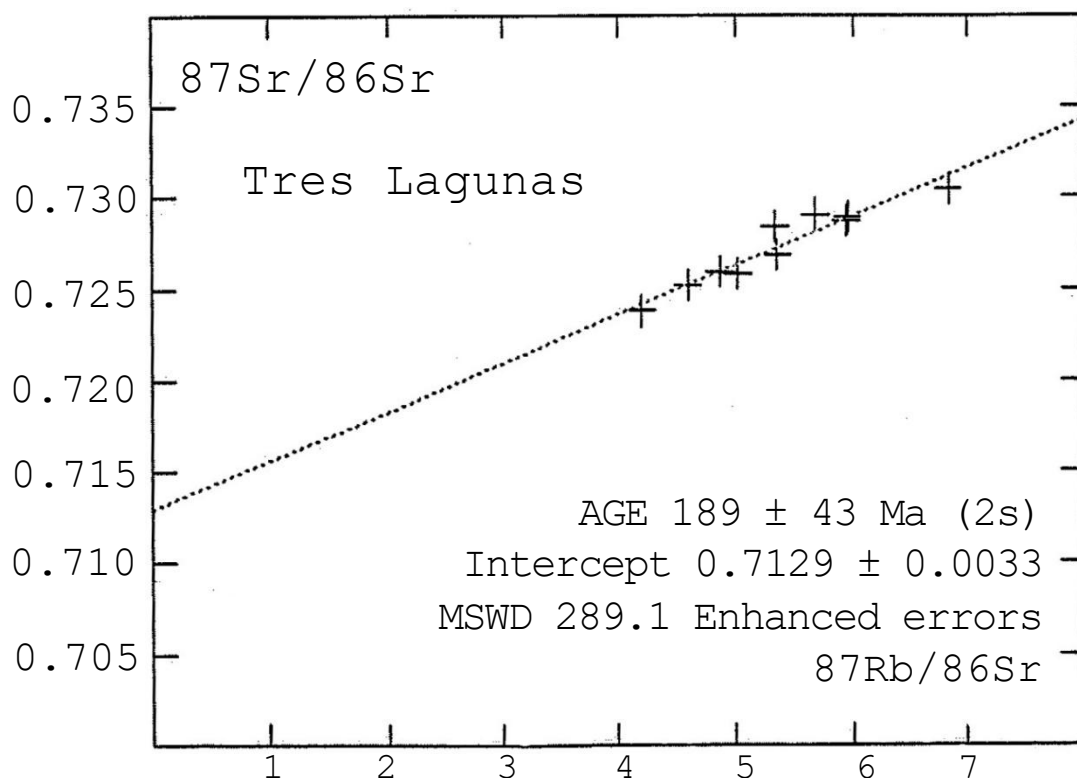


Figure 7b. As for Fig. 7(a) but without sample 14-F

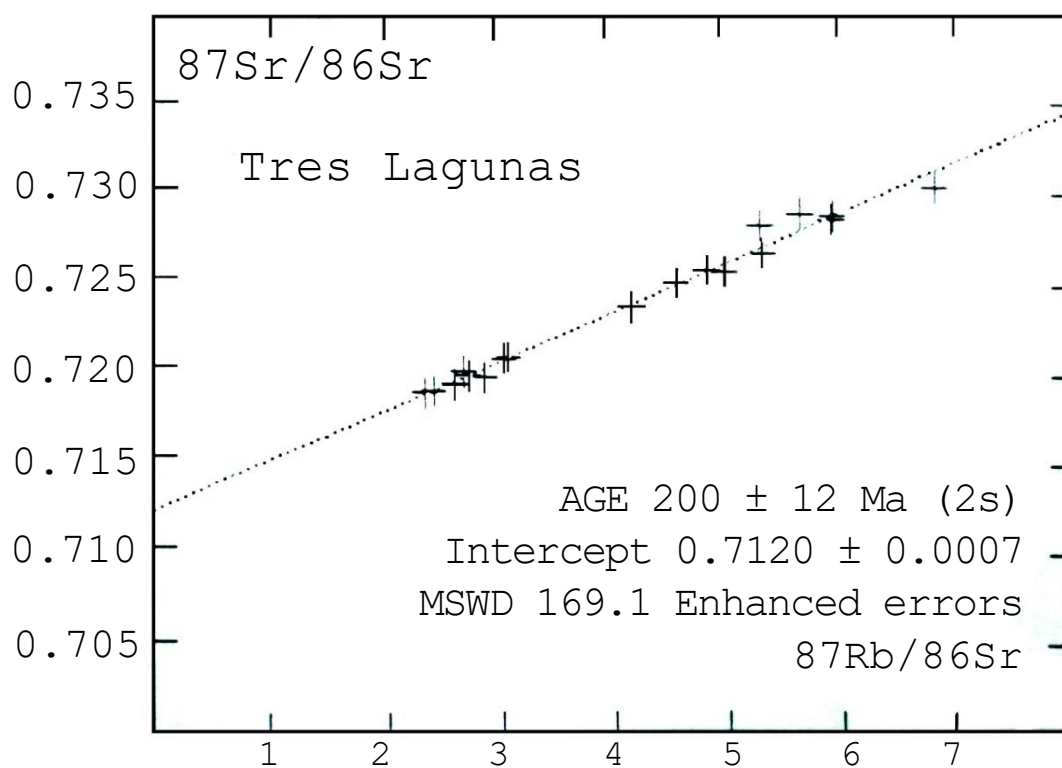


Figure 7c. Combined data from Figs. 7(b) and 5(b) combining the Tres Lagunas granite suites from Tres Lagunas and Malacatos

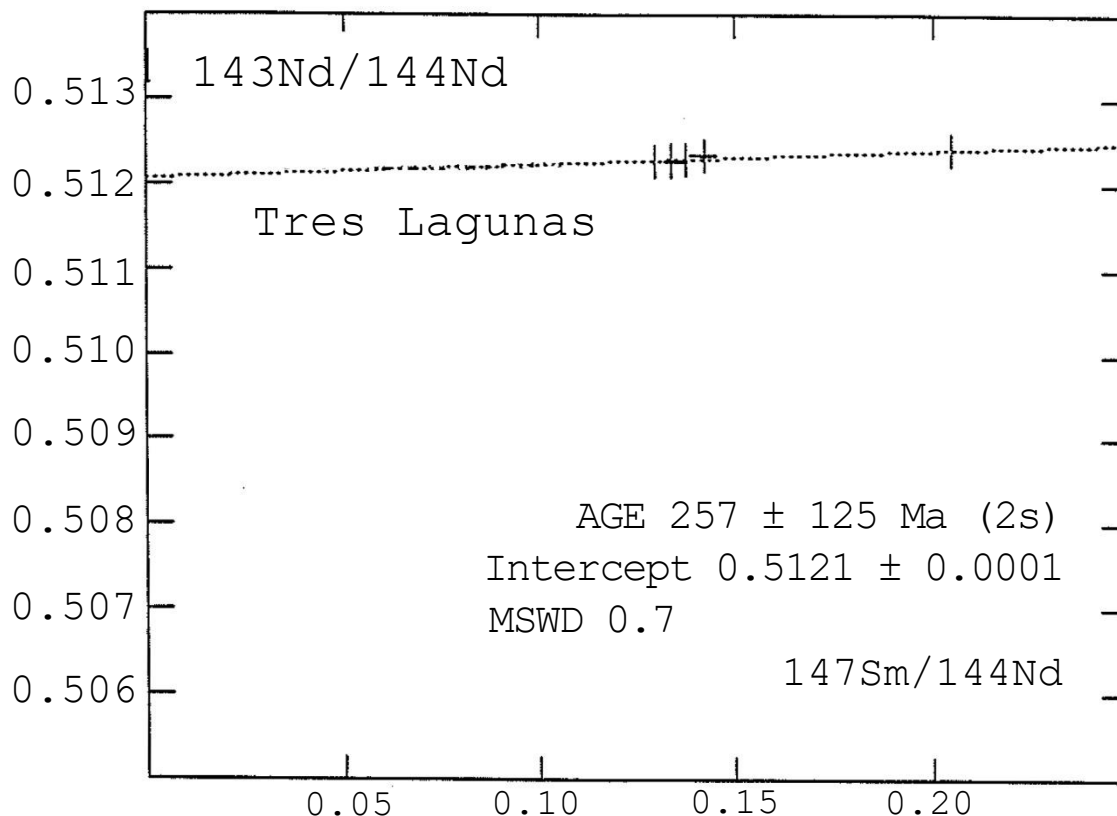


Figure 8. Sm-Nd isochron diagram for the Tres lagunas granite using garnet separates from samples CR/SH/89- 14 D, E, and F and whole-rock data from 14- D and F

Sm-Nd data: three of the samples collected (14-D, 14-E, and 14-F) contained garnet and these were separated out for Sm-Nd analysis with two whole-rock samples (14-D and 14-F). When plotted the data define a poorly constrained isochron with an age of 257 ± 125 Ma but with a low MSWD (0.7) (Fig. 8). The high errors are due to the restricted spread in the Sm/Nd ratios. The Rb-Sr data is probably a better indicator of the age of this intrusion.

K-Ar data (Table 4): both the biotites and the muscovites yield similar ages ranging between 70 and 60 Ma with the latter giving consistently older ages. Again, these are interpreted as reset ages.

- **CR/SH/89 – 15**

Granodiorite, north of Saraguro

Biotite and hornblende have been separated from this sample but due to the lack of time have not been analysed. The amount of hornblende may be insufficient for K-Ar analysis.

- **CR/SH/89 – 16 (A – D)**

Tres Lagunas granite, Peggy Mine

Although these samples were collected, the pervasive mineralized alteration of the rocks indicated that it was highly unlikely that an original crystallization age could be obtained and hence these samples have not been analysed.

- **CR/SH/89 – 17 (A – D)**

Mafic igneous complex, Tampanchi.

Samples 17-A and B are hornblende meta-gabbros and 17-C is a meta-basalt.

K-Ar data (Table 4): both the hornblende separates from 17-A and B and the whole-rock analysis from 17-C give similar ages of between 60 and 65 Ma. It is very unlikely these are the original crystallization age of these rocks and more likely to be the age of the deformation, which is closely associated with this complex.

- **CR/SH/89 – 18**

Andesite, Los Planes

This sample is ready for whole-rock K-Ar analysis but again due to the lack of time has not been analysed.

- **CR/SH/89 – 19**

Garnet tourmaline felsic pegmatite, El Oro province.

This sample comes from a locality very close to 07 above. The garnet from this sample was analysed in the hope that it would extend the range of the Sm/Nd data of the 06 samples above.

Sm-Nd data: the data from this sample has been plotted with that of the 06 samples (Fig. 4) and fortunately do extend the range of the Sm/Nd ratios considerably producing a well-constrained age (219 ± 22 Ma).

K-Ar data (Table 4): muscovite was separated from this sample and this gave an age of 189 ± 5 Ma, which is also similar to the other mica ages of the 06 and 07 samples.

All the remaining samples from **CR/SH/89-20** to **CR/MP-383A** listed in Table 1 have not been analysed. These samples were sent from Ecuador in May 1989 by Dr. John Aspden. Three of these suites were collected for Sm-Nd garnet - whole-rock analysis but the laboratories at NIGC were fully booked up and there was no possibility, even if time had been available, to do this work.

4. BRIEF SUMMARY AND CONCLUSIONS

A large proportion of the samples collected have been analysed and the results, although not as well-constrained as one might like, have provided some important information.

The results from the El Oro samples were the most successful and an important metamorphic event at 220 - 200 Ma has been defined by both the Sm-Nd and the K-Ar data. There is a remarkable similarity between the garnet gneisses of the El Oro and those from Papallacta in the north and Valladolid from the south of the Cordillera Real. The most important similarity being that all the samples contain abundant graphite with shiny lustre and in platy form such that it floats in water. It therefore seems likely that the El Oro and the Cordillera Real garnet gneisses were originally part of the same metamorphic complex. Although the garnets from the Cordillera Real have not fractionated the Sm/Nd and hence it has not been possible to prove that they are of the same age, the Rb-Sr data from the Sabanilla orthogneiss (CR/SH/89-12) does indicate that an important event at approximately 220 Ma was occurring in the Cordillera Real.

The age of the Tres Lagunas granite suite is relatively well-constrained at about 200 Ma from both the Rb-Sr and the Sm-Nd data. The initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (0.7120) is considerably higher than that of the Abitagua, Azafrán and Zamora granitoids (approximately 0.705) and clearly indicates that the Tres Lagunas granite has had a much greater crustal component involved in its genesis than the other granitoids. It is quite likely that the Tres Lagunas granite represents a crustal melt and related to the 220 - 200 Ma metamorphic event.

Another important feature of the data is the considerable number of reset ages between 80 and 50 Ma. This is clearly an important event and probably dating a phase of deformation within the Cordillera Real.

The data from the first phase of the geochronology programme carried out by Dr. Chris Rundle (Rundle, 1987a, 1987b, and 1988) has shown that the main intrusion of the typical Andean calc-alkaline granitoids (Abitagua, Zamora and possibly the Azafrán batholiths) occurred between 190 and 160 Ma. He has also shown that similar granitoids were emplaced at a much younger age of approximately 50 - 40 Ma ago. When the data from the two phases of geochronology are combined a very basic strato-tectonic history of the region studied can be compiled:

220	-	200	Ma:	High grade metamorphism and intrusion of the Tres Lagunas granites.
190	-	160	Ma:	Intrusion of the large Andean calc-alkaline batholiths (Abitagua and Zamora). Minor calc-alkaline plutonism continued till about 140 Ma.
80	-	60	Ma:	Major resetting of Rb-Sr and K-Ar isotope systematics most likely related to an important deformation event.
50	-	20	Ma:	Minor calc-alkaline plutonism (e.g. San Lucas, Portachuela plutons).

It is felt that during the planning of this project not enough time was allocated for the analytical work. Also, the NIGC laboratories are to be moved from Grays Inn Road to Keyworth in December 1989 and this put increased pressure on the use of the laboratories and hence not as many samples were analysed as hoped.

Table 1. List of samples collected for geochronology programme

All samples are prefixed by CR/SMH/89- except those from the last 6 localities: samples 664 to 819 are prefixed by CR/FV/- and samples 383 and 387 are prefixed by CR/MP/-.

No.	Sample	Quantity	Place
01	(A – D)	(4)	Garnet-bearing gneisses , Papallacta
02	(A – D)	(4)	Misahuallí volcanic rocks , Archidona
03		(1)	Granodiorite , Azafrán quarry
04	(A – J)	(10)	Monzonite , Marcabelí.
05	(A – B)	(2)	Amphibolite , Arenillas.
06	(A – E)	(5)	Garnet-bearing gneisses , near La Bocana.
07	(A – B)	(2)	Muscovite pegmatites , near La Bocana
08	(A – B)	(2)	Amphibolites , Portovelo.
09	(A – J)	(10)	Metagranitoid , north of Valladolid.
10	(A – D)	(4)	Garnet-bearing gneisses , Valladolid.
11	(A – I)	(9)	Tres Lagunas granite , north of Malacatos.
12	(A – J)	(10)	Sabanilla migmatite , Sabanilla.
13	(A – B)	(2)	Hb diorites , Río Chicaña.
14	(A – K)	(11)	Tres Lagunas granite , Tres Lagunas.
15		(1)	Granodiorite , north of Saraguro.
16	(A – D)	(4)	Tres Lagunas granite , Peggy Mine.
17	(A – D)	(4)	Tampanchi complex (gabbro), Tampanchi.
18		(1)	Andesite , Los Planes.
19		(1)	Muscovite pegmatite , La Bocana.
20	(A – B)	(2)	Amphibolites , Guarumales, Río Paute.
21	(A – C)	(3)	Garnet-bearing meta-sediments , Río Paute.
22	(A – B)	(2)	Granodiorite , Río Paute.
23	(A – D)	(4)	Garnet-bearing semi-pelites , Loja.
24	(A – D)	(4)	Garnet gneisses , Monte Olivo.
664	(D)	(1)	Granodiorite , Chuquiragua
681		(1)	Granodiorite , Río La Canela
815		(1)	Porphyry , Portachuela
819	(A – B)	(2)	Porphyry , Portachuela
387	(C)	(1)	Amphibolite , Tampanchi
383	(A)	(1)	Amphibolite , Tampanchi

Table 2. Rb-Sr data

Zone	Sample No.	Rb (ppm)	Sr (ppm)	Rb/Sr	$^{87}\text{Sr}/^{86}\text{Sr}$
Marcabelí pluton, El Oro	4A	129.8	120.3	1.1061	0.723104
	4B	128.0	124.6	1.0532	0.722230
	4C	121.1	121.4	1.0234	0.721802
	4D	113.1	104.2	1.1128	0.719046
	4E	129.2	103.5	1.2808	0.723970
	4F	142.2	122.7	1.1889	0.721411
	4G	126.2	118.3	1.0943	0.720337
	4H	127.4	108.71	1.2025	0.724581
	4I	116.4	104.0	1.1485	0.719453
	4J	138.5	102.8	1.3821	0.722461
Orthogneiss, pass between Loja and Valladolid	9A	139.6	79.2	1.7069	0.734322
	9B	136.6	73.3	1.9107	0.735133
	9C	115.7	64.5	1.8405	0.734817
	9D	112.0	83.6	1.3734	0.728841
	9E	141.0	86.6	1.6705	0.735410
	9F	134.9	97.6	1.4184	0.727562
	9G	122.7	118.0	1.0680	0.722429
	9H	222.6	147.5	1.5479	0.733774
	9I	130.8	134.1	1.000	0.724539
	9J	136.0	116.8	1.1935	0.728270
Tres Lagunas granite, Malacatos	11A	124.5	142.0	0.8995	0.719228
	11B	124.6	138.3	0.9250	0.719943
	11C	129.5	133.8	0.9927	0.719672
	11D	117.5	144.6	0.8338	0.718839
	11E	126.1	137.1	0.9427	0.719751
	11F	131.9	168.0	0.8053	0.718713
	11G	138.7	99.5	1.4295	0.721565
	11H	134.3	131.1	1.0507	0.720755
	11I	135.1	129.4	1.0669	0.720828
Sabanilla orthogneiss	12A	106.2	188.7	0.5771	0.718015
	12B	97.8	207.8	0.4825	0.716907
	12C	83.7	182.5	0.4706	0.716864
	12D	82.8	178.6	0.4754	0.716712
	12E	104.0	204.9	0.5202	0.717176
	12F	100.3	191.3	0.5378	0.717407
	12G	117.5	209.9	0.5742	0.717429
	12H	87.9	188.6	0.4782	0.716711
	12I	82.7	176.2	0.4816	0.716707
	12J	73.5	214.5	0.3514	0.715962
Tres Lagunas granite, Tres Lagunas	14A	189.7	95.0	2.0502	0.728677
	14B	174.8	106.9	1.6770	0.725903
	14C	186.7	93.3	2.0522	0.728931
	14D	182.7	102.0	1.8379	0.728399
	14E	175.1	97.3	1.8459	0.726842
	14F	217.6	85.7	2.6050	0.730760
	14G	186.3	97.7	1.9560	0.729059
	14H	197.0	85.8	2.3562	0.730438
	14I	173.7	103.2	1.7274	0.725799
	14J	169.8	109.9	1.5839	0.725207
	14K	144.7	102.1	1.4490	0.723795

Table 3. Sm-Nd data

All samples are prefixed by CR/SH/89-

Abbreviations: gt – garnet; ogt – orange garnet; pgt – pink garnet; wr – whole rock

Zone	Sample No.	Sm (ppm)	Nd (ppm)	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Sm}/^{144}\text{Nd}$
Garnet gneiss suite, Papallacta	1A (wr)	5.72	17.45	0.1982	0.512903
	1A (gt)	1.82	6.00	0.1834	0.512923
	1B (wr)	10.12	49.77	0.1229	0.512066
	1B (gt)	8.49	33.95	0.1512	0.512122
	1C (wr)	5.70	23.90	0.1441	0.512424
	1C (gt)	6.76	24.69	0.1591	0.512630
	1D (wr)	8.84	44.96	0.1189	0.512011
	1D (gt)	5.84	24.30	0.1453	0.511994
	1E (wr)	8.16	41.11	0.1200	0.512025
	1E (ogt)	8.18	36.30	0.1362	0.512053
	1E (pgt)	5.66	22.10	0.1548	0.512083
Garnet gneiss suite, El Oro	6A (wr)	5.59	30.63	0.1102	0.512075
	6A (gt)	4.56	14.52	0.1898	0.512220
	6B (wr)	7.63	37.41	0.1232	0.512132
	6B (gt)	6.62	23.54	0.1700	0.512170
	6C (wr)	6.33	34.64	0.1105	0.512074
	6C (gt)	4.22	10.73	0.2377	0.512280
	6D (wr)	7.92	40.13	0.1193	0.512111
	6D (gt)	5.53	16.74	0.1997	0.512245
	6E (wr)	7.23	38.83	0.1126	0.512099
	6E (gt)	4.83	14.93	0.1956	0.512237
Tres Lagunas granite, Malacatos	10A (wr)	5.11	24.09	0.1283	0.512056
	10A (gt)	8.24	33.85	0.1471	0.512013
	10C (wr)	7.07	31.57	0.1355	0.512067
	10C (gt)	7.46	36.92	0.1221	0.512038
	10D (wr)	6.69	33.11	0.1221	0.512049
	10D (gt)	5.94	26.72	0.1344	0.512052
Tres Lagunas granite suite, Tres Lagunas	14D (wr)	6.41	28.93	0.1339	0.512283
	14D (gt)	13.97	41.23	0.2048	0.512410
	14E (gt)	18.65	86.81	0.1299	0.512271
	14F (wr)	6.80	29.92	0.1374	0.512304
	14F (gt)	6.29	26.81	0.1418	0.512340

Table 4. K-Ar data and calculated ages

All samples are prefixed by CR/SH/89-

Abbreviations used: atm – atmospheric; rad – radiogenic; hb – hornblende; bt – biotite;

mosc – muscovite; wr – whole rock

Zone	Sample No.	K (%)	Atm ^{40}Ar (%)	Rad ^{40}Ar (nl/g)	Age (Ma)
Garnet gneisses, Papallacta	1A (hb)	0.294	76.51	4.301	342 ± 23
	1A (hb)	0.294	44.89	3.815	306 ± 10
	1B (bt)	5.817	27.13	243.146	844 ± 20
	1B (bt)	5.741*	9.29	253.597	881 ± 44
	1C (mosc)	6.965	50.93	20.373	73.7 ± 3
Marcabelí pluton, El Oro	4A (bt)	7.497	72.05	61.798	201 ± 12
	4A (mosc)	8.405	9.72	74.353	214 ± 6
	4H (bt)	7.651	7.06	70.042	221 ± 6
	4H (mosc)	6.997	74.92	55.487	193 ± 13
Amphibolites, Arenillas, El Oro	5A (hb)	0.370	91.23	1.062	72.4 ± 15
	5B (hb)	0.358	76.17	1.051	74.0 ± 6
	5B (hb)	0.358	81.36	1.080	76.0 ± 7
Garnet gneisses, El Oro	6B (bt)	6.26	28.24	54.375	211 ± 6
	6C (mosc)	7.04	11.08	61.822	213 ± 6
	6D (mosc)	5.68	14.82	48.492	207 ± 6
Pegmatitic gneisses, El Oro	7A (mosc)	8.45	32.94	76.941	220 ± 6
	7A (bt)	7.47	8.67	66.548	216 ± 6
Amphibolites, Portovelo	8A (hb)	0.07	88.72	0.602	224 ± 34
	8B (hb)	0.05	75.43	1.389	647 ± 37
Garnet gneisses, Valladolid	10A (mosc)	6.54	43.85	17.809	68.8 ± 2
	10A (bt)	7.02	28.51	23.672	84.7 ± 2
	10C (bt)	7.20	23.56	23.274	81.3 ± 2
	10C (mosc)	6.50	58.22	18.926	73.4 ± 3
	10 (bt)	7.41	32.83	24.085	81.8 ± 2
Tres Lagunas granite, Malacatos	11A (mosc)	7.45	44.87	29.642	99.6 ± 3
	11A (bt)	7.43	85.80	18.996	64.6 ± 9
	11B (mosc)	7.32	18.07	28.793	98.5 ± 3
	11B (bt)	7.43	67.56	18.531	63.1 ± 3
	11F (mosc)	7.75	32.59	30.615	98.9 ± 3
	11F (bt)	7.26	46.30	18.827	65.5 ± 2
Sabanilla orthogneiss, W de Zamora	12A (bt)	7.83	32.67	26.348	84.5 ± 3
	12A (mosc)	6.09	33.14	15.841	65.7 ± 2
	12C (bt)	7.78	15.23	26.784	86.4 ± 2
	12C (mosc)	5.72	50.44	14.864	65.6 ± 2
Diorites, Río Chicaña	13A (hb)	0.17	63.96	1.331	193 ± 9
	13B (hb)	0.16	81.95	1.230	187 ± 17
Tres Lagunas granite, Tres Lagunas	14D (bt)	7.225	25.96	17.619	61.7 ± 2
	14D (mosc)	6.29	61.01	16.812	67.5 ± 3
	14E (bt)	7.09	33.25	14.109	50.5 ± 2
	14E (mosc)	8.13	36.11	23.584	73.1 ± 2
	14F (bt)	7.26	43.42	17.725	61.7 ± 2
	14F (mosc)	7.77	47.33	21.186	68.8 ± 2
Tampanchi mafic-igneous complex, Tampanchi	17A (hb)	0.53	63.40	1.386	65.7 ± 3
	17B (hb)	0.51	71.69	1.229	61.2 ± 4
	17C (wr)	0.12	88.29	0.276	60.6 ± 10
Pegmatitic gneiss, El Oro (as for 07 samples)	19 (mosc)	8.51	15.30	65.994	189 ± 5

REFERENCES

- HARRISON S. M. (1989)** Report on a visit to Ecuador: geochronology sampling, Phase II. British Geological Survey Technical Report No. WC/89/10/R.
- KENNERLEY J. B. (1980)** Outline of the geology of Ecuador. Overseas Geol. Miner. Res., Inst. Geol. Sci. UK., No 55, 20 pp.
- RUNDLE C. C. (1987a)** Geochronology sampling in Ecuador, 1987. Report No. 87/12. British Geological Survey. Isotope Geology Unit.
- RUNDLE C. C. (1987b)** Rb-Sr analysis of rocks collected in May/June 1987 for the ODA-funded Cordillera Real Project, Ecuador. Report No.87/1. NERC Scientific Services, Isotope Geology Centre.
- RUNDLE C. C. (1988)** Potassium-Argon ages for minerals from the Cordillera Real, Ecuador. Report. No. 88/7, NERC Scientific Services, Isotope Geology Centre.
- STEIGER R. H. and JÄGER E. (1977)** Subcommittee on geochronology: convention on the use of decay constants in geo- and cosmochemistry. Earth and Planetary Science Letters, 36, 359-362.

APPENDIX 2c

Additional K/Ar determinations from the Cordillera Real by C. C. Rundle / Dr. S. Harrison

Sample No.	% K	% Atm	Rad40 $\pm$ %	Age (Ma) $\pm$ 2-sigma	Location
RM1 (hb)	0.593	59.3	3.161 $\pm$ 1.8	132 $\pm$ 5	Río Mayo batholith, E of Zumba (Río Mayo) (Granodiorite)
RM1 (bt)	4.64	15.9	19.29 $\pm$ 1.0	104 $\pm$ 3	
485 (hb)	0.481	37.6	3.247 $\pm$ 1.2	166 $\pm$ 5	Zamora-Río Mayo batholith, Porvenir, Q. de los Derrumbes (Granodiorite)
485 (bt)	4.04	52.0	28.73 $\pm$ 1.5	174 $\pm$ 6	
681 (hb)	0.916	22.5	5.708 $\pm$ 1.0	153 $\pm$ 5	Zamora-Río Mayo batholith, La Canela (Granodiorite)
681 (bt)	5.67	23.5	34.53 $\pm$ 1.1	150 $\pm$ 4	
18 (wr)	0.305	85.4	0.866 $\pm$ 6.1	72 $\pm$ 9	Los Planes, E of Zamora (Andesites)
15 (bt)	7.11	27.9	15.27 $\pm$ 1.1	54 $\pm$ 4	Río Pichinal, E of Saraguro (Granodiorite)

NB: 15 Bt was rather inhomogeneous and so there is a 4% error on the K-content which is reflected in the relatively high error on the age, nevertheless this is still significantly younger than any of the others. All other K results have the normal 1% error attached.

APPENDIX 3

Chemical analyses of plutonic and metaplutonic rocks from Ecuador

(Major elements, TiO_2 y P_2O_5 are given as wt%, all other elements as ppm)

Table 1. Abitagua batholith

SAMPLE	CR5A	CR5C	CR5D	CR5F	CR5I	CR6B	CR6E	CR6G	CR6J	CR6K
SiO₂	77.65	77.57	73.28	68.64	76.97	65.40	74.71	75.57	75.67	57.30
TiO₂	0.06	0.06	0.23	0.35	0.07	0.54	0.14	0.13	0.13	0.61
Al₂O₃	12.65	12.53	14.12	16.10	12.65	16.41	13.39	12.65	12.86	20.07
Fe₂O₃	0.47	0.62	0.88	1.25	0.49	1.39	0.81	1.10	0.66	2.08
FeO	0.29	0.28	0.93	1.60	0.33	2.32	0.92	0.65	0.72	3.86
MnO	0.08	0.08	0.05	0.09	0.03	0.09	0.07	0.07	0.05	0.16
MgO	0.00	0.00	0.33	0.75	0.01	1.17	0.17	0.00	0.00	1.79
CaO	0.38	0.39	1.62	3.02	0.62	3.23	0.58	0.47	0.54	5.94
Na₂O	3.87	3.80	3.82	4.73	3.95	3.51	3.94	3.77	3.84	4.75
K₂O	4.47	4.41	3.69	2.63	4.44	5.08	4.66	5.07	5.09	2.14
P₂O₅	0.03	0.03	0.09	0.14	0.03	0.19	0.05	0.03	0.03	0.32
LOI	0.32	0.35	0.65	0.89	0.28	0.69	0.61	0.21	0.26	0.83
Total	100.27	100.12	99.69	100.19	99.87	100.02	100.05	99.72	99.85	99.85
Fe₂O₃T	0.80	0.93	1.91	3.03	0.86	3.97	1.83	1.82	1.46	6.37
Cr	24	23	26	17	26	22	18	39	21	15
Cu	0	0	4	11	3	22	3	23	3	12
Ga	13	14	13	14	11	17	12	10	12	19
Nb	10	10	5	5	8	11	10	16	16	8
Ni	2	2	3	2	2	5	3	142	2	6
Pb	18	18	10	10	20	20	15	40	19	13
Rb	163	161	87	66	154	134	166	236	242	52
Sr	24	27	261	425	55	432	108	16	12	955
Th	17	14	4	3	19	5	16	30	22	0
V	7	0	22	29	1	52	8	7	3	73
Y	18	18	11	12	21	22	28	44	37	19
Zn	23	21	41	40	20	53	32	55	22	84
Zr	71	71	111	141	93	207	140	175	158	159
TiO₂	0.06	0.06	0.28	0.39	0.07	0.54	0.15	0.11	0.12	0.68
Ba	144	173	1515	1342	143	1218	407	39	74	1385
La	2	19	10	7	31	27	28	40	42	12
Ce	29	40	10	12	58	38	58	101	80	41
Nd	8	11	5	13	13	22	25	46	26	19
Cl	227	215	204	430	242	373	327	171	467	301
S	80	80	86	79	82	150	126	159	88	104
P₂O₅	0.03	0.03	0.11	0.16	0.04	0.22	0.06	0.03	0.03	0.40
TiO₂	0.07	0.07	0.29	0.41	0.07	0.59	0.17	0.12	0.14	0.73

Table 2. Zamora batholith

SAMPLE	CR16D	CR16E	CR16F	CR16G	CR16H	CR21A	CR21B	CR21D	CR21F
SiO₂	78.50	65.79	67.36	50.60	54.70	65.22	65.09	53.94	64.97
TiO₂	0.07	0.43	0.39	1.01	0.68	0.41	0.44	0.63	0.42
Al₂O₃	12.32	15.26	15.28	19.14	17.41	16.53	16.05	18.59	16.19
Fe₂O₃	0.53	2.42	2.08	4.66	3.08	2.03	2.03	3.10	1.85
FeO	0.20	2.32	2.05	4.58	4.63	2.14	2.24	4.73	2.18
MnO	0.04	0.11	0.10	0.13	0.13	0.09	0.08	0.20	0.12
MgO	0.00	1.69	1.39	4.00	4.90	1.52	1.57	3.93	1.76
CaO	0.35	4.23	4.07	9.20	8.09	4.82	4.24	7.07	2.71
Na₂O	5.31	4.07	3.99	3.82	3.37	3.78	3.88	4.24	4.08
K₂O	2.49	1.81	1.95	0.56	0.96	2.18	2.44	1.54	3.12
P₂O₅	0.07	0.10	0.10	0.11	0.12	0.15	0.14	0.20	0.13
LOI	0.27	1.34	1.34	1.94	2.02	1.14	1.47	1.86	2.28
Total	100.15	99.57	100.10	99.75	100.09	100.01	99.67	100.03	99.81
Fe₂O₃T	0.76	5.00	4.36	9.75	8.22	4.41	4.52	8.35	4.27
Cr	21	16	13	15	36	31	17	14	16
Cu	3	23	20	31	35	6	5	14	6
Ga	11	14	14	18	17	15	16	21	14
Nb	8	5	5	4	5	6	6	7	7
Ni	4	6	5	12	27	7	6	12	6
Pb	7	6	5	9	5	7	6	10	13
Rb	85	46	51	13	24	66	70	63	98
Sr	48	250	242	374	270	392	368	431	339
Th	38	6	6	2	0	6	8	0	7
V	9	105	88	326	211	64	91	169	76
Y	19	19	17	16	24	17	16	29	18
Zn	9	30	33	36	46	29	32	59	51
Zr	136	89	99	40	71	92	93	91	90
TiO₂	0.07	0.46	0.41	0.91	0.74	0.42	0.48	0.65	0.43
Ba	118	781	722	173	307	583	842	595	1133
La	25	7	4	3	3	10	6	0	7
Ce	41	11	23	11	16	16	6	3	14
Nd	9	16	26	11	17	8	11	9	11
Cl	391	607	552	699	560	354	420	425	366
S	85	88	87	385	217	93	99	126	125
P₂O₅	0.03	0.12	0.11	0.13	0.15	0.17	0.17	0.23	0.15
TiO₂	0.08	0.49	0.45	0.96	0.79	0.46	0.51	0.71	0.48

Table 3. Azafrán batholith and Sabanilla metapluton

SAMPLE	Azafrán batholith						Sabanilla metapluton			
	CR8A	CR8B	CR8D	CR8E	CR8F	CR8H	CR23A	CR23B	CR23C	CR23H
SiO₂	76.04	76.37	76.52	76.33	76.20	75.88	71.32	71.42	78.34	73.21
TiO₂	0.12	0.13	0.12	0.11	0.11	0.08	0.74	0.71	0.54	0.50
Al₂O₃	13.09	13.02	12.87	13.00	12.97	13.16	12.93	13.15	10.09	13.22
Fe₂O₃	0.67	0.43	0.56	0.54	0.52	0.62	0.53	0.16	0.32	0.57
FeO	0.47	0.53	0.47	0.53	0.53	0.44	3.70	3.78	2.13	2.94
MnO	0.09	0.08	0.08	0.10	0.10	0.11	0.06	0.06	0.07	0.10
MgO	0.06	0.08	0.10	0.07	0.03	0.03	1.93	1.75	1.09	1.36
CaO	0.83	0.82	0.52	0.75	0.73	0.54	2.23	2.38	3.74	1.47
Na₂O	3.93	3.85	4.02	3.96	3.96	4.34	2.24	2.40	1.44	2.30
K₂O	4.36	4.46	4.31	4.42	4.42	4.29	3.03	2.63	1.11	3.14
P₂O₅	0.04	0.04	0.04	0.04	0.04	0.04	0.17	0.20	0.16	0.16
LOI	0.42	0.41	0.42	0.39	0.40	0.32	1.05	1.10	0.74	1.03
Total	100.12	100.22	100.03	100.24	100.01	99.85	99.93	99.74	99.77	100.00
Fe₂O₃T	1.19	1.01	1.08	1.13	1.11	1.11	4.64	4.36	2.69	3.83
Cr	17	23	18	25	22	27	58	59	47	64
Cu	0	2	0	0	1	1	11	12	19	19
Ga	13	13	11	13	12	12	15	16	11	15
Nb	12	14	13	12	17	14	14	14	10	11
Ni	2	3	2	2	3	1	24	23	15	19
Pb	13	13	14	11	11	18	20	15	7	19
Rb	103	130	110	112	114	109	125	112	46	125
Sr	90	78	80	78	74	63	206	201	205	127
Th	9	13	11	11	15	11	9	9	8	7
V	10	14	1	7	0	4	103	91	49	78
Y	13	14	14	15	19	18	29	25	23	23
Zn	32	25	24	23	22	27	73	71	42	65
Zr	95	81	79	91	98	99	258	232	295	183
TiO₂	0.14	0.12	0.13	0.12	0.11	0.08	0.85	0.80	0.59	0.56
Ba	747	457	571	675	638	746	589	479	236	651
La	5	1	5	16	8	11	20	23	12	9
Ce	8	7	18	29	12	21	51	42	47	33
Nd	5	7	13	15	9	8	19	24	32	22
Cl	202	147	206	233	221	232	129	122	92	93
S	82	88	80	84	85	82	133	146	252	353
P₂O₅	0.06	0.05	0.05	0.05	0.05	0.05	0.18	0.21	0.18	0.16
TiO₂	0.14	0.13	0.14	0.13	0.12	0.09	0.91	0.88	0.64	0.60

Table 4. Marcabellí pluton, Valladolid metapluton and Tampanchi mafic complex

SAMPLE	Marcabellí pluton (El Oro)				Valladolid metapluton				Tampanchi mafic complex	
	SH4A	SH4C	SH4E	SH4I	SH9B	SH9E	SH9I	SH9J	383A	387C
SiO₂	72.04	71.87	72.73	71.98	74.20	73.77	73.09	72.47	57.02	44.53
TiO₂	0.49	0.45	0.54	0.34	0.51	0.53	0.48	0.51	1.21	0.93
Al₂O₃	14.17	14.37	13.60	14.67	12.93	13.71	13.41	14.17	14.73	16.91
Fe₂O₃	0.28	0.37	0.35	0.44	0.89	0.77	0.48	0.61	4.42	2.88
FeO	2.63	2.50	2.91	1.92	2.95	2.89	2.96	3.23	6.86	6.88
MnO	0.07	0.07	0.07	0.06	0.08	0.05	0.10	0.06	0.19	0.19
MgO	0.99	1.02	1.10	1.10	1.34	1.04	1.27	1.15	3.31	9.50
CaO	1.82	2.15	1.94	2.23	0.59	0.54	1.23	1.04	9.08	13.52
Na₂O	3.14	3.37	2.94	3.74	1.75	1.45	2.51	2.02	1.29	2.05
K₂O	3.04	2.63	2.93	2.76	3.22	3.15	3.28	3.28	0.16	0.85
P₂O₅	0.16	0.16	0.12	0.11	0.14	0.16	0.17	0.18	0.14	0.34
LOI	0.92	0.96	0.84	0.79	1.44	1.92	1.04	1.47	1.28	1.63
Total	99.75	99.92	100.07	100.14	100.04	99.98	100.02	100.19	99.69	100.21
Fe₂O₃T	3.20	3.15	3.58	2.57	4.17	3.98	3.77	4.20	12.04	10.53
Cr	37	31	32	25	84	87	104	77	1	329
Cu	17	6	6	9	13	10	18	13	124	90
Ga	13	15	15	14	15	18	17	18	17	17
Nb	8	9	10	7	10	11	10	12	5	7
Ni	12	9	12	12	197	174	207	150	15	78
Pb	18	16	17	15	25	20	23	31	15	22
Rb	132	123	132	118	141	143	131	139	0	3
Sr	123	123	104	104	76	86	134	118	169	542
Th	7	7	10	7	7	9	9	10	4	1
V	46	44	57	40	84	80	77	87	305	302
Y	27	23	25	25	21	23	22	26	29	23
Zn	55	54	58	42	66	74	76	67	75	116
Zr	166	167	188	119	135	191	160	157	64	66
TiO₂	0.55	0.52	0.62	0.35	0.61	0.71	0.62	0.61	1.17	0.91
Ba	492	276	385	444	1007	532	733	582	245	261
La	9	9	12	4	9	3	15	12	0	5
Ce	41	34	43	42	29	21	26	42	15	42
Nd	27	10	11	21	25	14	16	23	17	25
Cl	121	145	130	177	207	181	199	114	104	146
S	352	131	91	97	93	95	299	369	283	270
P₂O₅	0.16	0.17	0.12	0.11	0.17	0.21	0.17	0.19	0.18	0.43
TiO₂	0.58	0.57	0.66	0.38	0.67	0.77	0.67	0.66	1.24	0.97

Table 5. Tres Lagunas suite/East of Saraguro - Tres Lagunas area

SAMPLE	SH14A	SH14B	SH14D	SH14G	SH14H	SH14I	SH14J	SH14K
SiO₂	71.88	70.89	72.74	73.16	71.40	71.18	71.95	68.49
TiO₂	0.55	0.55	0.53	0.45	0.52	0.53	0.54	0.99
Al₂O₃	13.55	14.28	13.30	13.44	13.87	13.68	13.62	14.24
Fe₂O₃	0.76	0.91	0.45	0.50	0.74	0.79	0.89	1.89
FeO	2.57	2.38	2.62	2.20	2.53	2.48	2.29	2.74
MnO	0.08	0.07	0.07	0.06	0.07	0.07	0.06	0.09
MgO	1.03	1.04	0.96	0.79	1.01	1.04	1.04	1.25
CaO	1.65	1.73	1.47	1.41	1.54	1.59	1.58	2.84
Na₂O	2.53	2.85	2.49	2.55	2.66	2.49	2.50	3.56
K₂O	4.05	4.17	4.44	4.53	4.17	4.33	4.51	2.53
P₂O₅	0.18	0.18	0.19	0.19	0.20	0.19	0.19	0.28
LOI	1.23	1.17	0.96	1.01	1.23	1.20	1.09	1.06
Total	100.06	100.22	100.22	100.29	99.94	99.57	100.26	99.96
Fe₂O₃T	3.62	3.55	3.36	2.95	3.55	3.55	3.43	4.93
Cr	35	33	37	32	37	34	32	65
Cu	14	10	12	10	12	12	16	8
Ga	16	14	14	15	18	15	15	19
Nb	13	13	12	10	13	12	12	16
Ni	13	14	11	12	15	12	13	208
Pb	21	24	27	26	23	26	28	23
Rb	196	181	189	192	206	181	176	151
Sr	95	109	104	98	86	105	111	104
Th	15	13	12	10	14	16	16	22
V	57	57	57	52	59	46	54	89
Y	41	40	40	34	40	38	38	62
Zn	63	61	52	52	71	62	57	85
Zr	185	169	177	155	179	178	184	343
TiO₂	0.58	0.57	0.56	0.47	0.58	0.59	0.57	1.02
Ba	535	775	659	756	481	809	874	259
La	12	18	18	15	15	12	21	31
Ce	64	58	56	38	54	59	49	105
Nd	30	30	30	18	29	29	25	47
Cl	145	118	113	166	150	132	141	130
S	351	353	316	223	407	366	388	363
P₂O₅	0.19	0.19	0.20	0.19	0.20	0.20	0.20	0.29
TiO₂	0.62	0.61	0.60	0.51	0.63	0.62	0.62	1.10

Table 6. Malacatos, Peggy Mine-Sigsig area

SAMPLE	Malacatos						Peggy Mine–Sigsig area			
	SH11A	SH11C	SH11D	SH11E	SH11F	SH11H	SH16A	SH16B	SH16C	SH16D
SiO₂	70.20	70.52	69.85	69.97	68.51	70.01	71.01	70.99	71.38	71.09
TiO₂	0.71	0.68	0.72	0.64	0.75	0.71	0.55	0.55	0.58	0.59
Al₂O₃	13.67	13.64	13.53	13.98	14.10	13.87	13.67	13.73	13.47	13.56
Fe₂O₃	0.95	0.72	0.86	0.72	0.99	0.78	0.65	0.82	0.90	0.86
FeO	3.52	3.59	3.73	3.39	3.80	3.69	2.58	2.52	2.60	2.70
MnO	0.10	0.10	0.10	0.10	0.10	0.12	0.11	0.09	0.09	0.10
MgO	1.65	1.57	1.73	1.52	1.83	1.70	1.15	1.13	1.24	1.20
CaO	1.96	1.87	1.95	1.89	2.26	1.51	1.82	1.85	1.63	1.82
Na₂O	2.46	2.44	2.33	2.71	2.42	2.39	2.45	2.59	2.46	2.59
K₂O	3.18	3.25	3.14	3.19	3.28	3.44	4.21	3.82	3.92	3.56
P₂O₅	0.18	0.17	0.17	0.17	0.17	0.17	0.16	0.17	0.16	0.17
LOI	1.54	1.55	1.59	1.51	1.60	1.64	1.32	1.58	1.46	1.52
Total	100.12	100.10	99.70	99.79	99.81	100.03	99.68	98.84	99.89	99.76
Fe₂O₃T	4.86	4.71	5.01	4.49	5.21	4.88	3.52	3.62	3.79	3.86
Cr	107	95	101	89	99	92	39	35	39	38
Cu	23	29	24	16	23	19	13	13	13	13
Ga	20	17	17	16	17	19	14	15	16	16
Nb	11	12	11	11	13	12	11	12	12	12
Ni	212	217	199	206	210	180	13	12	13	15
Pb	22	20	22	23	18	37	45	33	25	22
Rb	128	132	121	129	134	138	150	158	171	153
Sr	146	136	147	139	171	133	132	114	115	106
Th	14	12	13	11	11	13	12	13	13	14
V	100	101	94	97	107	105	65	55	64	70
Y	33	32	34	29	31	30	32	35	34	38
Zn	78	81	77	69	81	148	51	60	58	59
Zr	193	197	200	168	210	197	178	175	181	188
TiO₂	0.88	0.80	0.88	0.74	0.87	0.84	0.57	0.56	0.57	0.62
Ba	818	818	861	781	844	982	1024	660	723	641
La	29	29	29	23	20	23	21	15	15	18
Ce	54	52	58	54	66	60	35	73	57	44
Nd	23	30	19	28	35	33	12	47	37	25
Cl	104	104	92	93	104	95	133	163	101	157
S	884	744	1275	1211	481	811	298	306	443	279
P₂O₅	0.19	0.19	0.19	0.18	0.19	0.20	0.15	0.17	0.15	0.17
TiO₂	0.94	0.87	0.95	0.80	0.94	0.91	0.61	0.60	0.62	0.67

APPENDIX 4

Petrographic studies (4a-4b)

PETROGRAPHY OF ROCKS FROM THE CORDILLERA REAL PROJECT

FEBRUARY-MARCH– 1990

BRITISH MISSION – INEMIN

Appendix 4a: English translation by Stalyn Paucar (2026)

APPENDIX 4a

PETROGRAPHY OF ROCKS FROM THE CORDILLERA REAL PROJECT

1. Introduction

The objective of this course is to learn how to identify the rocks of the Cordillera Real using thin sections. You will learn by looking at a collection of thin sections through a microscope; experience is the best training. I will try to keep the theory as brief as possible so that you can focus on the direct experience of the rocks from the Cordillera Real terrain. Furthermore, the Cordillera Real contains many special rocks, so these can be used for general training in petrology. The thin sections we will use are not of the highest quality, but they are the type of thin sections that a petrographer must use in practice.

When you look at a thin section, you must always study both the mineral and the texture. Sometimes the texture is the most important characteristic because it indicates how the rock was formed (e.g., plutonic, volcanic, metamorphic, sedimentary, etc.).

There are five types of thin sections with hand samples. These are:

- (a) Serpentinites and ultramafic rocks.
- (b) Granitic rocks and granitic gneisses.
- (c) Metavolcanic rocks.
- (d) Metasedimentary rocks.
- (e) Skarn rocks.

Because the Cordillera Real Project has been an investigation of the oldest rocks of this terrain, there are no examples of younger rocks or non-metamorphosed volcanic rocks.

2. The microscope

In this course, we will examine thin sections using a polarizing microscope. In this, the light passes through the polarizer (a sheet of polarized plastic) before reaching the thin section. This makes all light vibrate in the same direction. Additionally, in some tasks, we will insert a second polarizer between the lenses and the eyepieces; this is called the analyzer and is located at 90° relative to the lower polarizer. With these arrangements, we will observe the optical effect called interference colours and the position in which the mineral disappears called extinction. With the analyzer out, we can look at the colour, pleochroism, shape, relief, and cleavage of the minerals. With the analyzer in, we see the interference colours, twinning, and orientation of the minerals. With this information, we can recognize the minerals and also study the texture, which will help us identify the rocks and understand their history.

2.1 Colour

Many minerals are colourless in thin sections. Others are green, brown, blue, and even yellow. Some colours are very characteristic.

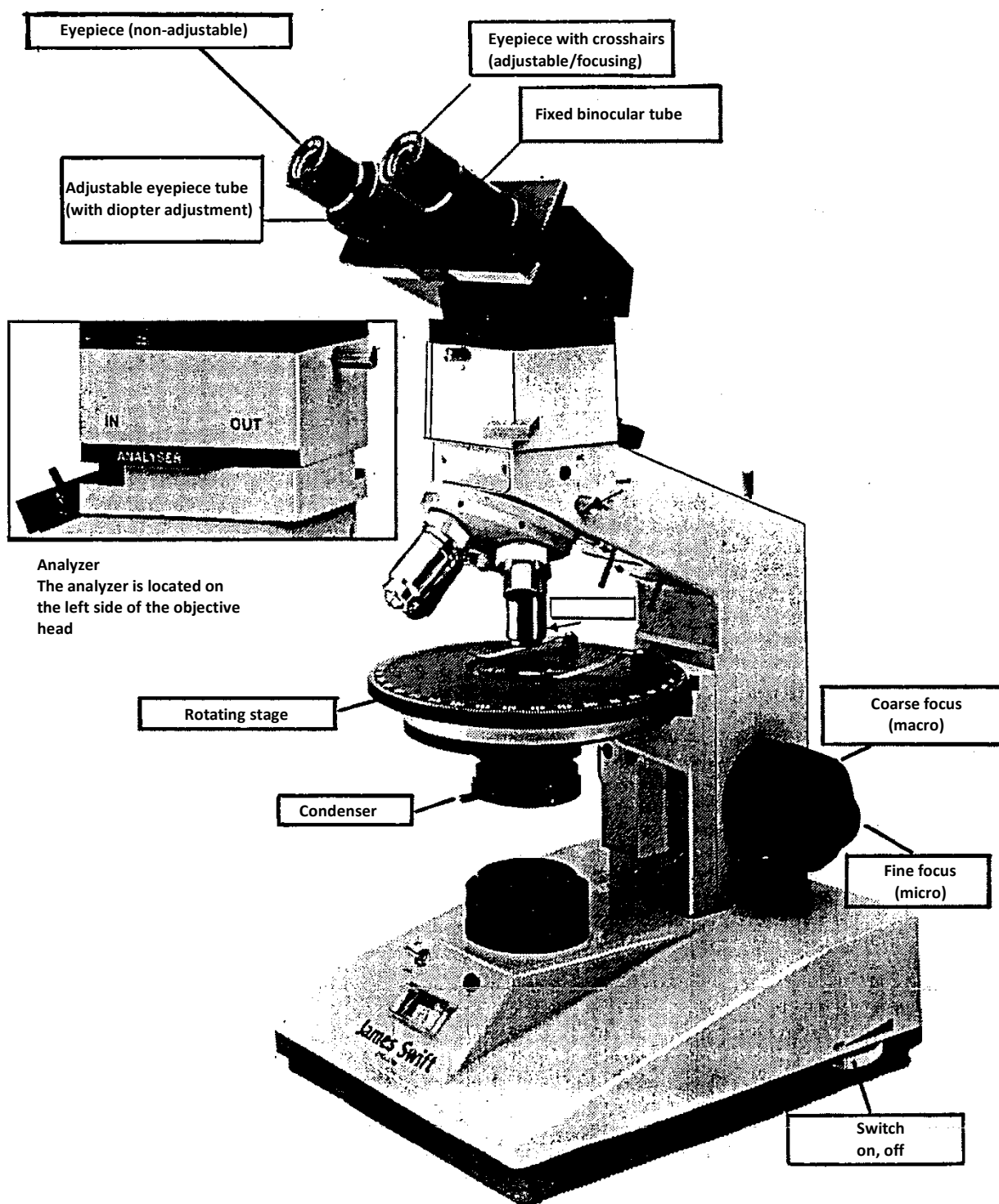


Figure 1. Polarizing microscope

2.2 Pleochroism

Some minerals change colour when they are rotated on the stage with the analyzer out. This is due to the way they interact with polarized light. This is very characteristic of certain minerals.

2.3 Shape

Some minerals frequently occur as crystals with characteristic shapes. Examples include micas (sheets), feldspars (tablets), and pyroxenes (prisms).

2.4 Relief

Minerals refract the light shone through them, and this can be measured by means of the refractive index. We will not do this, but the refractive index must be considered because the higher the index, the more the shape of the minerals appears to stand out from the thin section. Furthermore, by using the Becke line (the 'Becke test'), it is possible to determine if a mineral grain has a higher refractive index than the one next to it.

2.5 Cleavage

The crystals of many minerals have sets of planes of weakness called cleavage planes. These always have a geometric relationship with the crystal shape that we can see under the microscope.

2.6 Birefringence

With the analyzer in, we can see bright colours called interference colours produced by birefringence, a property caused by the complex refraction and polarization of light that takes place when light passes through the thin section. Some minerals provide stronger (higher) interference colours than others, and the intensity can be judged by referring to the interference colour chart. Low colours are seen as grey-white shadows, while stronger colours are seen as spectral colours.

2.7 Twinning

Crystals of some minerals, especially feldspars, contain planes (twin planes) in which the atomic structure of the crystal changes its orientation. With the analyzer in, this property produces an unusual pattern of colour interference.

2.8 Orientation

With the analyzer in, we can look at the optical orientation of the minerals. This has two characteristics. First, we look at the orientation of the crystals when they are at extinction (no interference colour). In some, the direction is parallel to the axis of the sheets or prisms (parallel extinction), but in others, it produces a characteristic angle (oblique extinction). In the second case, for example, we have a crystal aligned NW-SE on the microscope stage, then we insert the 'tint' plate (auxiliary plate) to see if the interference colour is strong or weak. This allows us to know if the crystal has positive elongation or negative elongation.

Also, at the most advanced level, we can use the strongest objective lens and the conoscopic lens to work with interference figures, in order to determine if the mineral is biaxial or uniaxial, its optical sign, and its optic-axial angle. This is not easy, and we probably do not have time to work on it in this course.

3. The thin section

The thin section is a rock slice that should be 30 microns (0.03 mm) thick. In reality, making thin sections is an art, and they are never perfect. The petrographer must recognize bad sections to avoid confusion.

Common flaws include:

- (a) Sections that are too thin or thick.
- (b) Sections varying in thickness.
- (c) Dust or air bubbles in the transparent resin used to fix the section to the glass.
- (d) Holes in the section where a piece of rock has been plucked from a cut thin rock,

Most of the thin sections used in this course have some of these problems.

4. Course notes

In the following notes, each of the five rock suites is presented, and a short description is given for each specimen. The descriptive notes are divided into four parts:

- (a) Sample number and location.
- (b) Sample name.
- (c) Mineral list.
- (d) Additional information.

5. Serpentinites and other ultramafic rocks

5.1 Introduction

Three groups of rocks are presented. (a) The Soledad and Urcuchocha serpentinites occur as thin belts of outcrops related to major thrusts. (b) The Peltetec rocks come from the outcrop belt of the ophiolitic *mélange*, which is the site of a major subduction suture within the Cordillera Real. In contrast, (c) the Tampanchi complex is currently interpreted as an Alaskan-type ultramafic intrusion complex. Economically, rocks of these types should be seen as possible enrichment sites for Cr, Ni, Au, and PGM (platinum group metals: Pt, Ir, Os, Rh, etc.).

(a) Soledad

- **RB-140A**

Serpentinite

Minerals: Antigorite, talc, chromite, magnetite.

Additional information: Massive, fine-grained, undeformed.

(a) Urcucocha

- **RB-353F**

Serpentinite with magnesitic veins.

Minerals: Antigorite, magnesite, talc, chromite, magnetite.

Additional information: Massive, magnesite and talc vein.

- **RB-353H**

Tremolitic rock

Minerals: Tremolite, antigorite.

Additional information: Harsh tremolite mesh with interstitial antigorite.

(b) Peltetec area

- **RB-59C**

Feldspathic peridotite

Minerals: Augite, antigorite, altered feldspar, altered olivine, magnetite.

Additional information: Undeformed.

- **RB-59B**

Altered gabbro with olivine

Minerals: Augite, chlorite, tremolite, hornblende, altered feldspar, quartz.

Additional information: Almost undeformed; strongly altered with augite relicts.

- **RB-225I**

Altered gabbro

Minerals: Plagioclase, calcite, muscovite, albite, quartz.

Additional information: Undeformed; the augite has been replaced by carbonate and albite veins.

(c) Tampanchi

- **MP-374**

Olivine pyroxenite

Minerals: Augite, olivine, hornblende, magnetite, serpentinite, talc.

Additional information: Undeformed; unaltered except for partial weathering of olivine into a talc-serpentinite mixture; hornblende replacing augite.

- **RB-247H**

Olivine pyroxenite

Minerals: Augite, hornblende, altered olivine, magnetite.

Additional information: undeformed; olivine altered to red material, hornblende replacing olivine.

- **RB-247M**

Hornblendite with plagioclase

Minerals: Hornblende, plagioclase, epidote, muscovite, albite.

Additional information: undeformed; partially altered plagioclase, pegmatoid rock.

- **RB-247F**

Hornblendite with plagioclase

Minerals: Hornblende, epidote, muscovite, albite, quartz.

Additional information: undeformed; pegmatite; all primary plagioclase has been completely weathered.

- **MP-370**

Basalt with hornblende

Minerals: Hornblende, plagioclase

Additional information: undeformed; fine-grained, hornblende phenocrysts including some with the shape of augite relicts.

6. Granitic rocks

Numerous granitic rock bodies are found in the Cordillera Real. Studies of the relative proportions of quartz, K-feldspar, and plagioclase indicate that the majority are monzonites, tonalites, and diorites.

The texture ranges from magmatic to metamorphic and mylonitic. Most of the rocks are I-type (derived from the melting of the upper mantle). Others, the Tres Lagunas granite suite, are S-type (derived from the melting of the lower crust during continent-continent collisions). I-type granites are associated with skarn, porphyry (Cu, Mo, Au), and epithermal (Au) types of mineral deposits. S-types are associated with deposits of tin, tungsten, niobium, lithium, beryllium, uranium, and other metals.

(a) Pimampiro pluton

- **RB-171A**

Tonalite with hornblende

Minerals: Plagioclase, quartz, biotite, hornblende, chlorite, opaque mineral.

Additional information: undeformed; very little alteration.

(b) Río Verde (Azafrán igneous complex)

- **46**

Quartz monzonite

Minerals: Plagioclase, quartz, orthoclase, hornblende, biotite, epidote, sericite, opaque material.

Additional information: undeformed; medium-grained, the epidote and sericite were formed by the alteration of the plagioclase.

(c) Chingual metapluton

- **MC-650C**

Granodiorite with hornblende

Minerals: Quartz, plagioclase, biotite, hornblende, orthoclase, opaque material, epidote.

Additional information: deformed; recrystallization at the grain boundaries.

(d) Oyacachi “blue quartz granite”

- **MC-462A**

Granite gneiss (orthogneiss with garnet)

Minerals: Quartz, sericite, muscovite, chlorite, garnet, opaque material.

Additional information: strong metamorphic fabric and complete alteration of feldspar and biotite.

- **MC-462B**

Granite gneiss (orthogneiss)

Minerals: Quartz, sericite, orthoclase, albite, chlorite, opaque material.

Additional information: metamorphic fabric and strong alteration.

(e) Tampanchi

- **MP-375B**

Mylonitic granodiorite

Minerals: Quartz, plagioclase, biotite, epidote, muscovite, microcline.

Additional information: sheared (protomylonite).

- **TAMP(B)**

Mylonitic granodiorite

Minerals: Quartz, plagioclase, biotite, muscovite, epidote, microcline.

Additional information: strongly sheared and recrystallized (mylonite).

- **TAMP(C)**

Sheared granite

Minerals: Quartz, albite, biotite, epidote.

Additional information: feldspar relicts and quartz crystals “survive” strong shearing; recrystallization of the rock.

(f) Tres Lagunas type

- **FV-343. Río Zavala**

Granite – mylonite

Minerals: Quartz, muscovite, biotite, carbonate, opaque material, albite, tourmaline, garnet.

Additional information: sheared and weathered.

- **853. Río Zavala**

Granite with biotite

Minerals: Quartz, albite, orthoclase, sericite, epidote, biotite, garnet.

Additional information: weathering of plagioclase; very little alteration.

- **FV-356**

Granite – mylonite

Minerals: Quartz, albite, orthoclase, muscovite, biotite, chlorite, carbonate, zircon, opaque material.

Additional information: strongly sheared and with some weathering.

- **FV-329**

Granodiorite with biotite

Minerals: Quartz, sericite, albite, orthoclase, biotite, epidote, garnet.

Additional information: some weathering and deformation.

- **FV-335**

Granite with biotite

Minerals: Quartz, albite, orthoclase, sericite, zoisite, biotite, muscovite, garnet, opaque mineral.

Additional information: weathering of plagioclase and weak deformation.

14 to 20

7. Metavolcanic rocks

Metamorphism deforms and completely destroys the characteristic textural features of volcanic rocks. Basaltic rocks are altered to chlorite schists and amphibolite. More acidic rocks sometimes retain a porphyritic texture, but tuffs can lose their igneous features. For this reason, we often have to make a conjecture about the origin of feldspathic schists and mica-rich schists. This small group of specimens illustrates many of these features. Basaltic sequences contain a Cyprus-type with copper deposits. Acidic volcanics contain polymetallic deposits of Kuroko-type and Roseberry-type. Volcanic rocks also provide the source of metals for polymetallic vein deposits.

(a) Near Monte Olivo

- **RB-179A**

Chlorite schist (metabasalt)

Minerals: Quartz, calcite, hornblende, epidote, biotite.

Additional information: complete alteration of basalt during the development of the schist texture.

(b) Río Palora

- **RB-108**

Meta-andesite with chlorite

Minerals: Quartz, albite, chlorite, epidote, opaque material, tourmaline, apatite, biotite.

Additional information: recrystallized during the development of the schist texture, but the feldspar phenocrysts have 'survived'.

(c) Atillo Macas

- **FV-876**

Metavolcanic schist – Loja Division

Minerals: Quartz, muscovite, chlorite, orthoclase, garnet, opaque material, epidote.

Additional information: strongly sheared schists probably of volcanic origin (perhaps an andesitic tuff).

- **FV-887 (1)**

Metavolcanic schist – Subandean volcanic Division

Minerals: Quartz, muscovite, biotite, opaque material, tourmaline, zircon.

Additional information: sheared schist whose possible origin is an andesitic tuff.

- **FV-887(2)**

Schistose meta-andesite – Subandean volcanic Division

Minerals: Quartz, albite, biotite, chlorite, muscovite, opaque material.

Additional information: schistose rock in which the feldspar phenocrysts have 'survived'.

- **FV-867**

Schistose meta-andesite – Alao-Paute Division

Minerals: Quartz, albite, epidote, chlorite.

Additional information: a lenticular schistose structure may have developed due to the widening of vesicles or welded tuffs.

8. Metasedimentary rocks

The metamorphism of sedimentary rocks develops a variety of quartzites, schists, and marbles. Schists are important because they frequently contain minerals that indicate the metamorphic grade with reference to the classic systems of Winkler, Miyashiro, Turner and Verhoogen, and others. The examples in this collection contain many of the indicator minerals including garnet, staurolite, andalusite, chloritoid, sillimanite, and kyanite. Two additional rocks are black marble rich in very fine-grained carbonaceous material of organic origin. Sedimentary rocks can contain enormous deposits of Zn, Pb, Cu and Ag, but the most common ones provide the source of metals for polymetallic vein deposits.

(a) Catamayo-Loja-Zamora. Loja division

- **FV-29A**

Phyllite

Minerals: Quartz, muscovite, graphitic material, staurolite.

Additional information: schist fabric populated with staurolite crystals.

- **FV-29B**

Staurolite schist

Minerals: Quartz, staurolite, muscovite, biotite, feldspar, opaque material.

Additional information: the abundant staurolite is post-kinematic.

(b) Cerro Hermoso area

- **RB-327**

Garnet-muscovite schist

Minerals: Quartz, muscovite, garnet, hornblende, opaque material, tourmaline, epidote.

Additional information: the garnet crystals were rotated before the late growth of hornblende.

- **RB-311**

Garnet-muscovite schist

Minerals: Garnet, quartz, muscovite, chlorite, hematite.

Additional information: the garnet crystals have pressure shadows; the chlorite is of late formation.

- **RB-309**

Andalusite schist

Minerals: Quartz, muscovite, andalusite.

Additional information: metamorphosed mudstone.

- **RB-313A**

Calcic schist with garnet-chloritoid

Minerals: Garnet, chloritoid, quartz, calcite, opaque mineral, chlorite.

Additional information: 'spongy' garnet crystals preserve the early fabric.

- **RB-323F**

Chloritoid schist

Minerals: Muscovite, chloritoid, tourmaline, quartz, rutile, hematite.

Additional information: pale blue chloritoid; strong blue-green tourmaline.

- **RB-324**

Sheared quartzite

Minerals: Quartz, sericite, muscovite, cordierite.

Additional information: sericite lenses stretched along the shear zone.

- **RB-310**

Black marble

Minerals: Calcite, opaque material (carbonaceous), quartz.

Additional information: fine-grained, with strong metamorphic fabric.

- **RB-302**

Black marble

Minerals: Calcite, opaque material (carbonaceous), quartz.

Additional information: fine-grained, with strong metamorphic fabric.

(c) Sabanilla basement

- **FV-44**

Sillimanite gneiss

Minerals: Sillimanite, biotite, quartz, albite, opaque material.

Additional information: high metamorphic grade.

- **FV-45**

Kyanite gneiss

Minerals: Kyanite, biotite, orthoclase, quartz, muscovite.

Additional information: high metamorphic grade.

9. Skarns

Skarns are rocks formed by metasomatism of limestones and other reactive rocks around an acidic and intermediate intrusions. Throughout the world, they contain very important deposits of gold, copper, zinc, and other metals. The specimens in this collection come from two parts of the Cordillera Real. Most are from the Llanganates skarns and related areas. These do not contain mineralization as far as we currently know. The two specimens are from the gold mine in the Nambija district and are thus representative of an important class of deposit known as “gold skarns”.

(a) Río Chalpi (Oyacachi)

- **MP-472E**

Diopside schist

Minerals: Quartz, orthoclase, muscovite, biotite, diopside, opaque material.

Additional information: Early stage of schist-to-skarn alteration.

- **MP-480E**

Garnet skarn

Minerals: Quartz, garnet, hedenbergite, hornblende, calcite.

Additional information: Weathering of skarn calcite.

(b) Sara Urco

- **MP-553C**

Skarn

Minerals: Hedenbergite, epidote, ferro-hastingsite, biotite, calcite, quartz.

Additional information: Weathering of skarn calcite.

- **MP-615**

Garnet skarn

Minerals: Garnet, prehnite, actinolite, muscovite, epidote, calcite.

Additional information: Complex weathering of early skarn garnet.

(c) Nambija gold district

- **JA-2**

Garnet skarn

Minerals: Garnet, quartz, calcite, diopside.

Additional information: Early garnet and diopside in late quartz and calcite.

- **JA-9**

Calcareous skarn

Minerals: Garnet, quartz, calcite, opaque minerals.

Additional information: Advanced weathering of calcite in rock with abundant gold.

(d) Río Mulatos (Llanganates)

- **RB-137**

Garnet skarn

Minerals: Garnet, quartz, hornblende, stilpnomelane, opaque material, apatite.

Additional information: Complex weathering with very dark stilpnomelane.

- **281**

Epidote skarn

Minerals: Epidote, calcite, hornblende, opaque minerals, quartz, biotite, titanite.

Additional information: The high concentration of opaque minerals is associated with the weathering of calcite in epidote skarn.

APPENDIX 4b

PETROGRAPHY OF SELECTED ROCKS FROM THE CORDILLERA REAL, ECUADOR

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1. Introduction

This petrographic report was compiled during a visit by the author in January, 1990, to the ODA-sponsored Cordillera Real project based at Quito. The work was carried out at the project office in INEMIN (the Instituto Ecuatoriano de Minería) using a conventional petrographic microscope. The 114 specimens examined had been selected by Dr. M. Litherland (Project Leader) from among the total collection assembled by the project since its initiation in 1986. They were collected during traverses across the Cordillera Real terrane by the project geologists Dr. M. Litherland, Ing F. Viteri, Santamaria, Dr. J. Aspden and Ing. M. Pozo Torres.

Dr. Litherland had selected specimens so as to present a series of thematic suites each relevant to the interpretation of the economic potential of a particular area. The topics addressed were as follows:

- (a) Central and Eastern Belt serpentinites and related rocks (potential for Cr, Ni, Au, Pt)
- (b) The Peltetec ophiolite belt (potential for Cr, Ni, Au, Pt).
- (c) The Oyacachi-Papallacta “aluminous granite” belt (potential for Sn, W).
- (d) The Tampanchi mafic/ultramafic complex (potential for PGE).
- (e) Nambija gold skarns (presently mined for gold).
- (f) Llanganates and related skarn fields (potential for Cu, Zn, Mo).
- (g) The Monte Olivo pegmatite belt (potential for Sn, W, Nb).

Previous petrographical/mineralogical reports by Dr. B. Beddoe-Stephens, Mr. J. Dangerfield and the present author had described rocks and alluvial gold grains from Nambija and other sites of mineralisation as well as granitoids from the Tres Lagunas S-type and other plutons. Additional reports by outside consultants had dealt with skarn lithologies from Nambija and Llanganates.

The following report is set out as a series of summaries of each group of specimens, as requested by Dr. Litherland. Individual thin section descriptions are not included, but copies of the rough notes are held by the project and by the author, and details are also recorded more formally on the project rock description forms. Previous results from the project are given in three annual Project Reports for 1987, 1988 and 1989 (unpublished) referred to below as the 1st, 2nd and 3rd Project Reports respectively.

The Cordillera Real Project is a bilateral Technical Cooperation project between the Governments of Ecuador (INEMIN: Ministry of Energy and Mines) and the United Kingdom (Overseas Development Administration). The present visit was made at the behest of Dr. J. Bennett of BGS Overseas Division. The author is grateful to Dr. and Mrs. Aspden for an introduction to the Country and the project, and to Lcda. Fabiola Alcocer Carrasco (Mission Secretary) whose help and patience were greatly appreciated.

2. Central and Eastern Belt serpentinites and related rocks

2.1 Soledad serpentinite

Seven thin sections were examined, from specimens RB-342, RB-296A, RB-136, RB-140A, RB-144G, 261 and RB-1G. In all of them a massive interlocking antigorite mesh is the major component, forming virtually the whole of RB-296A and RB-1G. Relict chrome-spinel grains occur infrequently, and micro-poikilitic secondary magnetite is a common accessory mineral. Fine-grained talc occurs as patches in some of the specimens, notably in RB-140A where it forms ca. 40%. Sub-poikilitic magnesite occurs in RB-144G and RB-1G, and is associated with development of shears in these rocks. RB-136 contains an opaque euhedral crystal, probably an octahedral interpenetrant twin, of a mineral of uncertain identity.

These rocks have formed by static alteration of an ultramafic rock, probably peridotite *sensu lato*. Formation of magnesite and to some extent magnetite took place during a late shearing episode expressed as a spaced shearing fabric seen in only two of the specimens. In general, the specimens provide evidence for static serpentinitisation and emplacement in their present crustal setting with only minor deformation.

In principle, ophiolitic serpentinites carry the potential for alpine-type Cr-Ni concentrations, but mineralogically the present specimens provide little additional indication of such mineralisation. Comparison with analytical results given in the second and third Project Reports confirms the probable presence of minor quantities of chrome-spinel, but high Ni-contents as in RB-136 and RB-1G appear to correspond with specimens with low contents of opaque minerals, suggesting that most of the Ni resides within the antigorite itself.

2.2 Urcuchocha serpentinite

Three thin sections of rocks from this body were examined; specimens RB-353, 343H and MP-518A. The thin sections indicate a massive serpentinite with patchy talc and tremolite alterations. The talc alteration is partially controlled by fracturing and shearing which post-date the original serpentinisations, and talc is accompanied by magnetite in the shear fabric. The specimen of tremolitic rock, RB-353H, shows no shear fabric and may result from alteration which pre-dates the shearing.

It is difficult to comment on the origin of a serpentinite on the basis of such a small sample. Economically, the significant opaque content of MP-58A complements good Cr and Ni whole rock values indicating at least some potential for the presence of enrichment of these elements in the serpentinite as a whole.

2.3 Baeza serpentinite

Two thin sections of specimens R-43C and R-43D were examined. Though this is a minute sample, it does show evidence for strong shearing of a serpentinite with Cr and Ni concentrations similar to the Soledad or Urcuchocha bodies. R-43D has a relict brecciated texture suggestive of erosion of the ultramafic “protolith” before re-burial and serpentinisation. Later tectonic shearing brought about local recrystallisation of massive antigorite together with formation of magnesite veinlets. Patches and disseminations of opaque minerals, probably magnetite and chromite are prominent in both thin sections.

2.4 Zumba complex

Thin sections of the following rocks were examined: FV-469A, FV-469B, FV-470A, FV-470B, FV-470C, FV-470D, FV-669F (two thin sections) and FV-669Q. Interpretation of the results will be greatly enhanced by reference to field relationships unknown to the present writer. However, with reference to comments in Litherland (1989: 3rd Project Report p. 17) it seems likely that FV-469 and FV-470 represent serpentinite and gabbro from the main part of the complex, while FV-669 represents xenoliths within the Río Mayo batholith.

The thin sections provide evidence of serpentinite with patchy development of a shear fabric with which veinlets of probable chrysolite and brucite are associated. Two specimens, FV-470A and FV-470C reveal the presence of unsheared tremolite or tremolite-talc rock. These carry relict olivine and also evidence of Ca-metasomatism after the tremolitic alteration. This metasomatism may have resulted from Ca-migration during serpentinisation (as a rodingisation), in agreement with the impression that here and in the “Baeza” serpentinite tremolitisation took place early, during or before serpentinisation. However, the evidence is not conclusive.

FV-469A is a quartz-gabbro which has suffered only limited deuteric or high-T metasomatic alteration. The lithology is difficult to ally with the serpentinite, and their juxtaposition may be tectonic in character.

FV-669 is a remarkable orthopyroxene rich norite hornfels in which the presence of hornblende and epidote suggests recrystallisation at moderate temperatures well below the solidus. Although the rock has an ultrabasic character, it is difficult to regard it as a baked serpentinite. Thus, for it to be seen as part of the Zumba serpentinite, it may be necessary to postulate incorporation of parts of the Zumba ultramafics into the Río Mayo batholith before serpentinisation. However, at the present stage I am unable to comment further on this question.

No evidence of good economic potential for the Zumba complex has been adduced, although the high Ni-content of the Ca-metasomatised tremolite rocks FV-470C (1138 ppm: 3rd Project Report) may be of interest if the mineralogical location of this amount of Ni could be determined. Litherland (3rd Project Report) considers the Cr and Ni values for these suites to be of little economic potential, but it may be worthwhile to determine the chemistry of chromite grains in the specimens at a later stage.

It is notable that these serpentinites occur as elongated strips of outcrop associated with major thrusts of the Cordillera Real nappe complex. The low degree of shearing is therefore surprising. Two explanations can be suggested. One is that static annealing of sheared fabrics may have taken place. The second, and more plausible, is that these massive specimens come from lenses of relatively undeformed rock within and between a series of shear zones which are themselves poorly expressed in the very limited exposure of the serpentinites.

3. The Peltetec ophiolite belt

A suite of 26 thin sections was examined representing rocks from three areas, as follows:

- Peltetec: (RB)- 57, 53, 59A, 59B, 59C, 59D, 59E, 59F, 59H, 59I, 60A, 60D, 225B, 225C, 225D, 225E, 225I, 225J, 225K.
- Penipe: (RB)-209A, 209B, 209G.
- Huarguallá: (RB)-87D, 87F, 87H, 87J.

These sub-suites will be considered separately before any overall considerations are made.

3.1 Peltetec sub-suite

The 19 thin sections examined indicate a variety of rock types including “high-level”, hypabyssal and plutonic varieties. “High-level” lithologies comprise altered basalts (RB-57, RB-58, RB-59F, RB-59I, RB-60A) and volcanoclastic sediments (RB-59E, RB-60D). Hypabyssal rocks are represented solely by one specimen (RB-225B). Plutonic types include serpentinite (RB-225E) and variously altered gabbros (RB-59B, RB-59C, RB-59D, RB-59H, RB-225C, RB-225D, RB-225I, RB-225J), possible norite (RB-59A) and peridotite (RB-225K).

The range of lithologies is compatible with an ophiolite origin, although the distribution of rock types probably represents the haphazard sampling pattern resulting from the intermittent exposures. Wide variation in the degree and style of alteration indicates rocks with differing petrogenetic histories being brought together in the present mélange. However, hydrothermal brecciation and veining in two samples is more probably of later, post-mélange origin.

Three of the specimens are of sparsely microporphyritic basalt dominated by a dark, only incipiently devitrified groundmass which in one specimen is flow foliated. One specimen, by contrast, is a highly porphyritic, vesicular rock. Phenocrysts appear to be plagioclase and probable olivine in the quasi-aphyric rocks, but plagioclase and augite in the porphyritic rock. Alteration is only moderate, to quartz, albite, carbonate, sericite, chlorite and epidote for the most part; compatible with reaction with heated seawater.

In the hydrothermally brecciated basalt specimen (RB-60A) intense brittle fracturing has allowed formation of an orthogonal network of veins with considerable dilation of the rock. Mortar-textured quartz veins intersect with cross-fibre epidote-quartz veins, and late, obliquely foliated carbonate veinlets are accompanied by deposition of carbonate granules on mortared quartz grain boundaries. The carbonate veinlets carry fibres of possible anthophyllite where they cut earlier-formed epidote. Relative timings of these veins are debatable, especially when seen in conjunction with the adjacent brecciated sedimentary rock (RB-60D).

One specimen (RB-59F) differs radically in being a strongly foliated, schistose metabasaltic rock whose primary mineralogy and texture have been obliterated. Indeed, its inclusion as a basalt is in itself questionable; minute lenticles of siliceous or serpentinitic material may be clasts of altered basalt or relict altered pyroxene crystals derived from a plutonic precursor.

The two specimens of sedimentary rocks are both basaltic, volcanoclastic varieties. One is a micro-breccia in which subangular basalt and dolerite clasts are set in groundmass of comminuted basaltic material. The other (RB-60D) is a quartz-feldspathic siltstone fractured and invaded by albite-epidote veins carrying patches of fine grained “mylonitic” quartz as well as patches of carbonate and a brown-hued clay mineral. In contrast to RB-60A, the mylonitic material appears here to pre-date the epidote veining.

The single dolerite specimen shows spillitic alteration of a microgabbroic textured rock

The plutonic rocks can be divided into those in which alteration has destroyed almost all the primary constituents, and those in which augite is substantially unaltered.

Among the former group are rocks in which primary grain boundaries are preserved, indicating static alteration. Alteration products of pyroxene include dark-stained carbonate, probably brucite, and micro-scale tremolite-chlorite intergrowths with a distinct boxwork structure. Plagioclase alteration products include chalcedonic pseudomorphs and complex quartz-hematite-sericite pseudomorphs. Other alteration products include carbonate and albite. The brucite rich rock (RB-225I) may be altered norite rather than gabbro *sensu stricto*. Other plutonic rocks with deformed fabrics comprise foliated tremolitic serpentinite and sheared gabbro rich in brucite (after pyroxene) and periclase (isotropic pseudomorphs after feldspar). Specimen RB-59F (see above) may also belong in this subgroup.

The sub-group of less altered plutonic rocks comprises melanocratic olivine-gabbros and peridotite. In general, plagioclase in these rocks has been replaced by pseudomorphs of brown, sub-opaque, cryptogranular material, possibly made up of quartz and hematite. Olivine is replaced by pseudomorphs of serpentine or of chlorite-quartz. Pyroxene, however, has resisted alteration and displays the strong birefringence and oblique extinction of augite. Orthopyroxene was not specifically identified. Sparse opaque grains occur embedded in the margins of olivine pseudomorphs or within augite crystals. Alteration of these rocks has been a static process, though fracture veinlets of chlorite-carbonate-hematite and of albite-sericite were noted infrequently. One specimen shows zones of penetrative comminution probably due to forceful gas penetration and resultant fluidisation, suggesting interaction with near-surface eruptive activity considerably later than the original formation of the rock.

3.2 Penipe sub-suite

The three specimens represented here comprise a deformed volcanoclastic mudstone, a serpentinite and a pyroxenite. In the mudstone (RB-209A) lenticles preserving an early foliation are set in a strongly foliated matrix; the early fabric is effectively perpendicular to the later, but it is not clear whether the earlier is actually a bedding fabric or not. Mineral constituents of this rock include hornblende, quartz and probable feldspar, suggesting metamorphism at moderate temperature. The serpentinite shows an early, massive mesh fabric crossed by magnesite veinlets which were deformed in subsequent shear deformation of the rock. The pyroxenite is a massive, coarse grained augitic rock with quartz-epidote in veinlets and minor augite replacements.

3.3 Huarguallá sub-suite

The four specimens each represent a distinct lithology. One is an intensely deformed and altered basaltic rock similar to specimen RB-59F from Peltetec. In the present specimens of fresh crystals of brown pleochroic augite are present, but their paragenesis is uncertain. A second specimen has a similarly schistose fabric but, in this case, static silicification has taken place after the shear deformation, resulting in preservation of the foliation in a cherty jasperoid lithology.

The third specimen is feldspathic olivine-pyroxenite showing alteration of feldspar and olivine but preservation of augite, an alteration style very like that seen in other melagabbroic and pyroxenitic specimens in this suite.

The fourth specimen is a composite breccia. Two stages of brecciation are indicated, the earlier sedimentary, the later hydrothermal. In the later stage loosely packed mm- to cm-scale fragments of sedimentary microbreccia and dolerite are cemented by a chlorite-albite matrix, and the rock is also cut by later, dilational, cross-fibre veins of coarsely crystalline albite. The microbreccia fragments contain clasts of augitic silty mudstone, augite and cherty mudstone set in a muddy matrix of similar composition; this early brecciation evidently took place in a volcano-sedimentary environment.

3.4 General comments

Taken as a whole, the suite of specimens from the Peltetec belt form a consistent set of ophiolitically related lithologies. The basalts and sedimentary rocks could represent the upper part of oceanic crust. The dolerite could represent intermediate levels in which dykes are dominant. The plutonic rocks could represent sub-crustal magma-chambers. Other rocks could represent alteration and deformation on shear zones before incorporation into the *mélange* or during subsequent tectonic movements. No continental or arc-derived rock types were encountered.

It is unwise to speculate, on the basis of the present petrographic examination, about the economic potential of the Peltetec belt. I note that Litherland (1988: 2nd Project Report) records up to 1.6 ppm Au in rocks from this belt, and thus considers that it merits prospection for precious metals and steel industry metals. While this may well be so, the juxtaposing of diverse high-level and plutonic rocks must limit the possibility of large coherent bodies of rock with primary metal enrichment. It may be necessary to look for areas where secondary, post-*mélange* mobilisation has taken place, or to consider Peltetec rocks as a protore for later, Cenozoic mineralisation.

4. Oyacachi - Papallacta “Aluminous granite” belt

Eight thin sections were examined representing granite and country rock lithologies. Specimens MP-461B, MP-462A and MP-462B represent granitic rocks from the Oyacachi area. Specimens SH-01B and MP-625 are granitic rocks from the Papallacta area; specimens SH-01C1, SH-01C2 and SH-01E are country rocks from the Papallacta area.

4.1 Oyacachi area

The specimens are deformed and altered garnet-granite reminiscent of descriptions of rocks of the Tres Lagunas granite suite (e.g. report by J. Dangerfield in the 3rd Project Report). Original granitic textures have been destroyed save for the irregular, re-entrant forms of pink garnet crystals. The rocks have acquired a gneissose fabric expressed in the general elongation of the interlocking areas of quartz and altered feldspar. Plagioclase shows strong sericite alteration accompanied by clusters of well crystallised muscovite flakes, and also by minor chlorite. Where sericitisation is advanced, deformation has resulted in a foliated, lepidoblastic fabric in pseudomorphs. In MP-462A plagioclase has also been partially replaced by quartz. Biotite has been replaced by areas of coarse muscovite, or of chlorite-muscovite-quartz-opaque. Garnet is mostly unaltered, but in MP-461B areas of intimate sericite-epidote intergrowth may in part represent alteration of coarse areas of garnet.

Compact primary opaque grains of probable magnetite-ilmenite occur in small numbers, but more conspicuous are disseminations of platy opaque grains, possibly of hematite or ilmenite. Accessory minerals include zircon and apatite.

One specimen, MP-462B, shows a more advanced style of alteration. Stumpy prisms of pale brown-violet tourmaline are a minor constituent. The abundant platy opaque grains are accompanied, in areas of feldspar alteration, by chlorite, swarms of minute rutile grains, and areas of minute pale-green prisms interpreted as possible chloritoid.

The rocks evidently represent aluminous granite with mineralogical characteristics similar to the "S-type" Tres Lagunas suite, and as such may indicate the northward extension of these rocks. Alteration took place during metamorphic deformation, and involved interaction with the metamorphic fluid to give a complex pattern of alteration with elements of greisenisation and of equilibration with regional greenschist metamorphism. No cassiterite or W-minerals were identified.

4.2 Papallacta area

A specimen of garnet-granite from this area proved to be a biotite-garnet-granite similar to the Oyacachi rocks described above, showing a similar pattern of deformation and alteration. However, in this example, SH-01B, strain and grain boundary suturing is less pronounced than in the above examples, biotite shows only minor muscovitisation, plagioclase shows partial quartz replacement and alteration to sericite and (?clino) zoisite with preservation of albite rims, and K-feldspar is little altered but displays a complex pattern of strain-induced fine twinning. Late alteration is represented by infrequent carbonate hairline veinlets accompanied by blue-green tourmaline, and epidote and rutile are associated accessory minerals. The second specimen, an example of "blue-quartz" granite, is a similar garnet-bearing rock in which the quartz shows intense mortar texture and internal strain which probably are the cause of its blue body colour.

It should be pointed out that in all these granite specimens potassic feldspar appears to be subordinate to plagioclase, so that the rocks are more correctly called monzogranite.

The remaining three specimens of country rocks from the Papallacta area include a garnet-mica-schist of possible sedimentary origin. The other two are banded sericitic schists of probable volcanic origin, as intermediate to acid tuffs perhaps. Sericite bands alternate with garnet-chlorite-quartz bands at the cm-scale. In one specimen the garnet-bearing bands are also enriched in opaque grains. This specimen, SH-01C(2), displays a lenticular structure owing to pinching and minor displacement of the bands on an oblique, spaced cleavage. In these rocks the presence of apparently prograde chlorite suggests that, despite the presence of garnet, the grade of regional metamorphism is probably about middle greenschist.

5. Tampanchi mafic/ultramafic complex

Twenty-one rocks selected by Dr. Litherland to represent distinct lithology-based parts of the complex are as follows:

Ultrabasic rocks:	(MP)-377, 379.
Pyroxenites:	(RB)-247G, 247H, 247J; (MP)-374A, 374B, 386B.
Amphibolites/gabbros:	(RB)-247B, 247F, 247N, 247M; (MP)-370, 380, 383A, 439.
Acid rocks:	375B, TAMP-A, TAMP-B, TAMP-C, TAMP-D

5.1 Ultrabasic rocks

The two specimens comprise a serpentinite and an olivine-clinopyroxenite. The serpentinite has a bastite texture in which preservation of relict cleavage traces may suggest replacement of orthopyroxene rather than olivine, implying alteration of orthopyroxenite or websterite. However, relict crystal forms are not typically prismatic, so it remains possible that olivine has been replaced. This rock hosts relict primary opaque oxide grains, and may thus be a source of Cr and other ultramafic-related metals. The olivine-clinopyroxenite is more typical of the Tampanchi complex in that augite is a dominant mineral, while olivine is subordinate and orthopyroxene very minor or absent (orthopyroxene would be recognised optically by low birefringence and straight optical extinction in prismatic sections, also, if sufficiently ferrous by the presence of characteristic pleochroism). This rock is also characteristic of the suite in that it displays pervasive partial alteration of augite to green amphibole. In this example the amphibole has a pale body colour and is probably actinolite rather than hornblende. Throughout the suite amphibole became more important, leading to hornblende-gabbro and hornblende-basalt in which it apparently was a mafic liquidus phase to the exclusion (possibly through total resorption) of pyroxene.

5.2 Pyroxenites

Following on from the olivine-clinopyroxenite already referred to, these specimens comprise a set of hornblendic augitites with only minor olivine and possible minor orthopyroxene (not specifically proven) in a minority of the rocks. Serpentine was identified as a minor alteration product in two of the rocks, and goethitic pseudomorphs after probable olivine in a third.

The dominant petrographic element of these rocks is a massive, cumulus aggregate of augite crystals generally of 1-3mm prism-thickness. The crystals have suffered varying degrees of hornblende replacement, but are otherwise substantially unaltered. Twinning on (100) is common but orthopyroxene exsolution (diallage) was not observed. Hornblende is present ubiquitously. It occurs as small (ca. 0.1-0.5 mm) pockets scattered through augite crystals which in 3-dimensions may link up in a vermiform fashion, as patches formed by alteration of the margins of adjacent augite crystals, and as poikilitic areas in which subhedral augite crystals are embedded.

Apart from the hornblende, alteration is limited. Opaque granules which occur at grain boundaries and within hornblende cleavage planes are probably hematite or another iron-oxide mineral.

Specimen MP-374B is exceptional in that a tongue of interlocking andesine crystals cuts across the augite aggregate. The form of this suggests fissuring of the aggregate at or above solidus temperatures, resulting in rapid precipitation of feldspar from magma supersaturated in aluminium. The feldspar tongue is itself penetrated by a vein-like growth of augite deposited during further rupturing of the feldspar body itself. Finally, the feldspar has undergone partial alteration to epidote at a much lower temperature.

5.3 Amphibolites and gabbros

These rocks comprise a variety of hornblendic lithologies. Coarse hornblendite is made up of an aggregate of quasi-pegmatoid prisms. In this lithology labradorite and, possibly, a less calcic plagioclase occur as crystals of comparable grain size or intergrown with quartz in interstitial pockets. The hornblende shows weak chloritisation, and the feldspar shows partial to complete alteration to epidote and muscovite. Opaque minerals are effectively absent from this pegmatoid variety of rock.

Specimen RB-247B is a tremolite rock in which very coarse grained pegmatoid tremolite prisms appear to represent wholesale replacement of the pegmatoid hornblende lithology.

Specimen RB-247N is a distinct lithology made up of a massive cumulus aggregate of 1 mm sized hornblende crystals. Opaque grains, probably of magnetite, are common at hornblende grain boundaries. The hornblende has suffered minor epidote alteration. An allied lithology is hornblende-gabbro (MP-380) of typically plutonic gabbroic texture but with hornblende in the role usually taken by pyroxene. The amphibole is unaltered, but the labradorite shows partial alteration to epidote and muscovite. Opaque grains are infrequent in this rock.

The remaining two rocks, MP-370 and MP-383A, are of an unusual hornblende-basalt, possibly the dyke or extrusive equivalent of the hornblende-gabbro. In both examples hornblende forms ca. 50% by volume. Both have a somewhat granoblastic, sub-idiomorphic to allotriomorphic, character to the groundmass. MP-383A is aphyric, and is tentatively seen as a hornfels. However, MP-370 is porphyritic, with subhedral phenocrysts of hornblende 1-2 mm in diameter. Opaque granules are a minor disseminated part of one rock but are almost absent in the other. MP-370 is almost free of alteration, but clinozoisite granules occur thinly disseminated in MP-383A.

5.4 Acid rocks

These specimens represent a major change in lithology from the other Tampanchi specimens examined. The five rocks present differing degrees of cataclastic deformation and hornfelsic alteration of a suite of acid plutonic rocks. So far as can be judged the original rocks varied from monzogranite to diorite. Original mafic constituents have been obliterated, but the absence of garnet is perhaps significant in that it supports the impression that these rocks should not be linked with the Tres Lagunas - Oyacachi suite of S-type granitoids.

Following the conventional classification of crushed rocks, the specimens vary from protocataclasite, through cataclasite, to mylonite.

Hornfelsing is conspicuous in one specimen (TAMP-C) in which extremely fine-grained biotite is abundant. In other rocks, shreds of biotite, often accompanied by muscovite and epidote, are common. Specimen TAMP-D is distinct in that post-deformation alteration has been intense possibly reflecting a more mafic original lithology. Plagioclase shows partial clinozoisite alteration, and a pale tremolitic amphibole is common. Further alteration of this rock is expressed in the presence of biotite, muscovite, chlorite, epidote and carbonate, and also by partial alteration of the pale amphibole to a brown-stained, sub-opaque material.

5.5 Discussion

It can be argued that the Tampanchi suite of rocks represents a hornblendic, calc-alkaline plutonic complex, and is not of itself ophiolitic in character. The ultramafic to gabbroic rocks suggest a continuum in which augite and hornblende are dominant. At one extreme is the serpentinitised orthopyroxenite or dunite, whose relationship with the other rocks is uncertain. It could represent one end-product of the plutonic differentiation, or be xenolithic material transported up from deeper, possible upper mantle, levels. This rock apart, the trend is from massive, fresh cumulus clinopyroxenite (augite) towards increasing proportions of hornblende and, at a later stage, to increasing importance of plagioclase, leading to augite-free hornblende-melagabbro. Augite evidently was the initial liquidus phase, but was resorbed and replaced by hornblende so that at the solidus hornblende and calcic plagioclase were forming. The surviving hornblendic pyroxenites may be massive crystal aggregates that resisted complete replacement by the amphibole. The two fine grained rocks comprise a hornblende-labradorite-clinozoisite hornfels and what appears to be a hornblende-phyric hornblende-basalt in which it is possible that the hornblende phenocrysts formed by alteration at around solidus temperatures of initial augite phenocrysts, prior to eruption.

The specimens appear to represent gravimetric or flow differentiation of mafic phases from an undersaturated basalt magma in which high PH_2O caused hornblende rather than augite to be stable at the solidus. Thus, augite is accompanied by olivine, while many rocks are dominated by the relatively low-silica amphibole, and quartz was recorded only in pegmatoid hornblendite.

These basic rocks are little altered and free of deformation. It is therefore difficult to see how the cataclastic granitoid acid rocks could be related to them temporally or petrogenetically. Rather, it is likely that they represent older “basement” plutonites which suffered crushing and local hornfelsing before or during events which lead up to emplacement of the Tampanchi mafic complex.

Dr. Litherland suggests comparison of the Tampanchi complex with Alaskan-type ultramafic complexes. Certainly, if a concentric pattern of lithologies grouped about a dunitic or peridotitic core can be demonstrated, then this comparison is attractive. However, there are some inconsistencies apparent in a simple equating of these complexes based on comparison with Alaskan complexes as described by Taylor (1967). At Tampanchi it is possible that a core of orthopyroxenite rather than dunite is present; further field research will be required to seek incompletely altered material in order to resolve this question. Anorthite, characteristic of Alaskan complexes, has not been recorded at Tampanchi. On this point, however, it is worth pointing out that in the plagioclase-bearing pyroxenite (MP-374B) clinozoisite alteration of plagioclase will have modified the original feldspar composition, and similarly in the melagabbro (MP-380) a certain degree of feldspar alteration has occurred. Typical Alaskan clinopyroxenites contain ca. 10-20% magnetite; opaque contents of the Tampanchi pyroxenites are very low, which is puzzling, although one suspects that differential weathering may have led to a sampling bias towards layers of massive, unaltered rock. Alaskan ultramafic complexes are intruded into larger gabbro plutons, but no pyroxene-gabbro occurs in the present suite of thin sections unless the hornblende-metagabbro represent alteration of this component. Moreover, the style of alteration in which augite remains unaffected is reminiscent of that seen in pyroxenite from the Peltetec ophiolite mélange.

On present evidence, it appears that Tampanchi may be rather different from the classic Alaskan complex in some respects, though a broad similarity is present. Furthermore, it should be repeated that the present small suite of specimens is a poor basis for drawing such conclusions. The present evidence indicates an undeformed, and perhaps relatively young pyroxenite ultramafic body. The apparent high proportion of hornblende rocks is more reminiscent of the type Alaskan bodies rather than their counterparts in the Ural mountain (cf. Taylor, 1967), which is perhaps a little discouraging with regard to the potential for PGE concentrations of economic importance. However, such generalisations are of dubious validity, and further examination of the complex is required before its mining potential can be properly assessed. From the petrological point of view there is a clear need for further work here, including additional sampling, detailed mapping, ore mineralogy, microprobe analyses and whole-rock analyses.

5.6 References

TAYLOR H. P. (1967) The zoned ultramafic complexes of southeastern Alaska. In, Wyllie H. P. (ed.). "Ultramafic and related rocks". Wiley, New York, 97-112.

6. Nambija auriferous skarns

The three specimens examined (JA2, JA7, JA9) represent successive stages in the retrogressive alteration and related mineralisation of skarn rock. JA2 is skarn in which little retrograde alteration has taken place. Grandite crystals are embedded in strain-free poikilitic quartz accompanied by infrequent pockets of similarly poikilitic carbonate.

Pyroxene grains (probably diopside-hedenbergite) occur within both quartz and garnet, accompanied (and probably replaced by) carbonate grains in the latter situation. The garnet occurs as massive patches and as individual euhedral, forming some 70% of the rock.

In detail, three main stages of garnet growth are apparent in JA2. The middle stage is colourless in thin section, displays 1st-order birefringence and shows both fine concentric growth zoning and sector extinction. Within euhedral growths of this middle stage lie cores of early colourless, birefringent, garnet. The cores are geometrically complex, possibly made up of clusters of small granules, and are intergrown with pyroxene and carbonate grains. The late garnet is colourless to pale green in thin section, and may be more andraditic than the earlier stages. It forms subhedral to quasi-spherical shells around the euhedral middle stage crystals. It displays 1st-order birefringence and, often, a radiating pattern of optical extinction. It may also display fine, concentric growth zoning. The middle and late growth stages are typically separated by a thin shell of isotropic garnet which takes the form of crescentic septa where there is a geometrical misfit between the shapes of the middle and late growths.

JA7 is similar to JA2, but here there is a brecciated texture. Clasts and grains of early-middle garnet are embedded in, and back-veined by, unstrained poikilitic quartz and subordinate carbonate. Late-stage garnet forms thin rims around earlier garnet patches and also forms small euhedral crystals of its own. Moderate retrograde carbonate alteration is shown by small grains within early-middle stage garnet and in the quartz, all probably formed by pyroxene replacement; no pyroxene was recorded in this thin section. The carbonate grains in the quartz are hematite stained, creating areas of penetrative red staining in the rock.

JA9 shows advanced carbonate alteration. Grandite-mosaic quartz skarn remains as relict patches in the fine-grained semi-massive retrograde carbonate. Opaque grains lie thinly dispersed through the carbonate alteration.

This small sample of three rocks shows features characteristic of the gold skarns (Meinert, 1988) in that mineralisation (opaque grains) occurred during late carbonate-rich alteration of grandite-rich skarn. Birefringence and concentric zoning are common in skarn grandite, as are complex, multi-stage growth patterns (e.g. Meinert, 1982). No indication of the pre-skarn protolith is apparent. However, it would be useful to know if the growth pattern of Nambija grandite was towards iron enrichment, and if a similar pattern is present in the pyroxene (in that pyroxene in the probably recrystallised quartz may be more iron-rich than that embedded in early garnet).

A cursory examination of poikilitic quartz and carbonate in JA2 shows that both contain 2-phase (liquid-gas) fluid inclusions. Homogenisation tests combined with analyses of co-existing garnet and pyroxene could help define T and fO_2 conditions of skarnification (cf. Meinert, 1982). Previous fluid inclusions analyses carried out on these samples by Dr. T. J. Shepherd (2nd Project Report) indicate that the quartz in JA2 formed at ca. 200° C. This is much lower than the temperature at which the coexisting garnet might be expected to form, indicating that the poikilitic quartz has completely recrystallised during the retrograde alteration. Fluid-inclusion results for all three samples indicate a progression to slightly lower temperatures and considerably increased salinity with progressive alteration and mineralisation.

6.1 References

MEINERT L. D. (1982) Skarn, manto and breccia pipe formation in sedimentary rocks of the Cananea mining district, Sonora, Mexico. *Econ. Geol.* 77, 919-949.

MEINERT L. D. (1982) Gold in skarn deposits a preliminary overview. In, *Proceedings of the Seventh Quadrennial IAGOD Symposium*, 342-367.

7. Llanganates and related skarn-fields

7.1 Introduction

Skarns and related protoskarns outcrop in the form of high-level klippe separated by areas of lower topography over some 200 km along the eastern flank of the Cordillera Real. The first of these was discovered by Dr. Litherland in the Llanganates area (1st Project Report). Blocks of skarn from this field were located in Río Mulatos and described petrographically by B.P. Minerals International (report incorporated in the 1st Project Report as Appendix 5). Outcrop samples of Llanganates skarn were described by Dr. Pat Williams for B.P. Minerals (report incorporated in the 2nd Project Report as Appendix 5).

The present report deals with small suites of thin sections of specimens from other skarn fields in this group. In addition, data from the previous reports are summarised. Finally, an overview is taken in which similarities between the suites of specimens are discussed.

It is important to appreciate that access to the skarns is very difficult owing to the elevation, isolation and adverse climatic environment of the outcrops. Many of the specimens are from boulders in the river gorges which drain the cordillera:

- (a) Río Mulatos – Llanganates area
- (b) Río Verde
- (c) Urcucocha
- (d) Río Quijos
- (e) Oyacachi
- (f) Sara Urco

7.2 Río Mulatos

Eight specimens were examined as hand specimens and thin sections for B.P. Minerals International Ltd. The rocks were collected from the river which is eroding the outcrop area of the Llanganates skarn field.

Two of the specimens were of calc-alkaline plutonic rocks carrying primary hornblende and biotite. Both show pervasive saussuritic (epidote-sericite) plagioclase alteration. One shows secondary growth of biotite particularly evident in marginal replacement of primary hornblende. Both show extensive chloritisation of primary biotite and formation of minor epidote and pyrite (disseminated; <2% vol.). Formation of the secondary chlorite was accompanied by minor deformation indicated by buckling of altered biotite and by concentration of chlorite into widely spaced shear fractures.

One specimen is a biotite-chlorite rich schist with blue-green tourmaline particularly developed as rosettes embedded in areas of otherwise clear quartz mosaic. Calcitic is confined to minor late fractures in this rock.

One specimen is a chlorite-phyllite in which sub-rounded 4-8 mm garnet crystals have grown by replacement of the foliated groundmass. In detail, these garnets are partly altered, with pale chlorite rims, inner rims of chlorite crowded with opaque matter, and cores of garnet strongly veined by chlorite: the chlorite is retrograde, and the nature of the original, presumably pelitic mineralogy is uncertain.

The remaining specimens are calcic skarn rocks in which early skarn alteration has been strongly modified in two episodes of retrograde alteration. Initial skarn alteration resulted in formation of pale pink garnet (probably grandite, although there are no analyses to prove this) and colourless to apple green diopside-hedenbergite. Early retrograde alteration gave epidote, amphibole and, in one specimen, orthorhombic humite. Late alteration gave extensive formation of carbonate by replacement and deposition in fractures. The amphibole, green to deep-blue green hornblende and ferrohastingsite, probably formed later than the epidote. The carbonate, including calcite and ankerite, is accompanied by chlorite, magnetite, pyrite and pyrrhotite. Total opaque contents are 2-6 %, so the rocks can hardly be described as “magnetite-skarns” as stated in the B.P. report.

7.3 Llanganates skarn outcrops

The 1987 report by Dr. P. J. Williams of the University of London (2nd Project Report Appendix 5) describes 31 outcrop specimens from the Llanganates skarns in the Río Mulatos area. In addition to detailed specimen descriptions, Williams provides a concise summary of his findings which is reproduced here.

Two specimens of igneous rock, a diorite and a plagiophyric “microdiorite” (dacite) display cross-cutting zones of epidote imposed on an earlier foliated sericite alteration fabric. They have probably been involved in the skarn alteration process.

Sedimentary rocks include marbles and schists. The marbles contain grossular, and one specimen carries minute grains of red sphalerite and other sulphides. The schists include genuinely sedimentary and probable metavolcanic (tuffaceous) rocks.

Most of the specimens are partially skarn altered or thoroughly skarn altered. The skarn mineralogy is very variable although the range of minerals present is limited and is generally consistent from specimen to specimen. Variation in protolith rock types has exerted considerable control, resulting for instance in monomineralic clinozoisite, epidote and tremolite rocks. However, in general the mineral assemblage is made up of grandite, hedenbergite, epidote, hastingsite amphibole, quartz, carbonate (likely calcite) and opaque minerals. Minor constituents include biotite, chlorite, apatite, adularia and titanite. Textural relationships consistently indicate that distinct prograde and retrograde stages can be made out. However, within these stages paragenetic indications are inconsistent and difficult to interpret. Within the prograde assemblage early “proto-skarn” actinolite is overprinted by grandite, hedenbergite, epidote and ferrohastingsite. Epidote and the amphibole often appear to have formed later than the garnet and pyroxene, which may have grown at the same time. However, it seems probable that there was overlap in the growth periods of these minerals, leading to the inconsistencies referred to. Biotite appears to represent a minor component of K-metasomatism late in the skarn alterations and is also seen as post-kinematic porphyroblasts grown in actinolite-rocks. The retrograde stage is dominated by carbonate and quartz deposited as veinlets and replacements. Apatite and adularia occur as trace constituents in this stage, and chlorite is important locally. Opaque minerals, comprising magnetite, pyrite, pyrrhotite and chalcopyrite according to Dr. Williams, are widespread. Most can be related to the retrograde stage of alteration, but some probably formed with the calc-silicates of the prograde stage.

Finally, a single specimen of tourmaline-quartz rock was described. The tourmaline varies from deep blue-green to pale pink-brown, suggesting a dravitic variety.

Major and trace element analyses of this suite by the ICP-Optical Spectrometry method were sponsored by B.P. Minerals International and are given in the 2nd Project Report Appendix 1. Variation of the major elements such as Ca and Mg is broadly in accord with what would be predicted from the rock types, but the results are suspiciously low in many cases. For instance, quartz-grossular rock (RB-285C) is recorded as having only 0.47% Al, 2.47% Ca, 0.04 % Mg and 0.50% Fe; these figures are very difficult to believe and must cast some doubt on the quality of these data. Bearing this in mind, the analyses indicate the following maximum concentrations:

Element	Concentration	Rock
Fe	%	16.64
Mn	ppm	32581
Co	ppm	51
Ni	ppm	483
Cu	ppm	1347
Zn	ppm	4279
Cd	ppm	22
Pb	ppm	278
Ag	ppm	5.8
As	ppm	294
Sb	ppm	6
Bi	ppm	8
W	ppm	23
Au	ppb	46

None of these values are especially high, but there is some indication of Zn and Cu enrichment related to the metasomatism. Also, the highest Au corresponds with the highest As, suggesting hydrothermal deposition of these elements in a specimen (RB-286A) of massive fine-grained epidote-quartz schist with early-metasomatic actinolite and traces of hematite. There are thus hints of hydrothermal metal enrichment in the Llanganates skarns, but nothing of obvious economic significance.

7.4 Río Verde

This area lies some way south of the main Llanganates area. Two specimens were examined. One is interpreted as a metasomatised tuff in which minute actinolite grains occur abundantly through massive fine-grained sericite rock crossed by a veinlet of epidote, quartz and tremolite. The other is massive fine-grained epidote rock carrying patches of quartz + amphibole and other areas with interlocking sheares of amphibole prisms. The amphibole here is pale blue-green, possibly actinolitic hornblende. This latter specimen could be described as an epidote-skarn.

7.5 Urcucocha

This area lies north of Llanganates. Seven specimens were examined. Five are of massive, fine to medium grained epidote skarn, one of a dacitic meta-volcanic rock, and one of quartz-muscovite schist which may be metamorphosed tuff. The skarn specimens show retrograde alteration to chlorite and quartz and then to carbonate. Minor hematite and K-feldspar are associated with the carbonate. Blue-green actinolitic hornblende is also spatially associated with the carbonate in one of the specimens.

The meta-dacitic rock comprises sheds of muscovite set in a granoblastic mosaic of quartz and subordinate albite. Epidote granules are common, and isolated clusters of chlorite flakes may be pseudomorphs after amphibole. The quartz-muscovite metatuffaceous schist carries accessory quantities of epidote, brown tourmaline and opaque grains.

The meta-volcanic rocks suggest a schistose pre-cursor to the epidote skarn.

Chemical analyses of skarn rocks from the Urcucocha, Río Quijos and Río Oyacachi were made by ACME Laboratories of Vancouver, sponsored by B. P. Minerals International. As with the Río Mulatos - Llanganates analyses, the major element figures look suspiciously low. For instance, epidote rocks from Urcucocha gave results of 0.94-2.49 % Al, 1.75-6.32% Ca and 1.36-4.65 % Fe. Even so, bearing this in mind, maximum recorded metal contents are given as:

Element		Urcucocha	Río Quijos	Río Oyacachi
Fe	%	4.65	9.15	7.88
Mn	ppm	1604	1521	3918
Co	ppm	23	236	14
Ni	ppm	53	46	22
Ca	ppm	49	12	114
Zn	ppm	578	45	297
Cd	ppm	1	2	1
Pb	ppm	20	30	17
Ag	ppm	0.4	0.4	0.4
As	ppm	12	78	18
Sb	ppm	5	6	13
Bi	ppm	3	5	14
W	ppm	3	5	14
Au	ppb	43	24	3

These figures are generally lower than those for the Llanganates suite, and give little encouragement from the economic point of view. However, Mo shows significant if perhaps isolated enrichment in two of the Urcucocha samples: MF-514A, 5092 ppm Mo; MF-514B, 3383 ppm Mo. The thin section of one of these specimens shows it to be massive, fine-grained epidote skarn in which platy opaque grains are associated with hairline veinlets of carbonate. Mo enrichment is thus associated with retrograde alteration of the skarn.

7.6 Río Quijos

Dr. Litherland considers that blocks of skarn in this river may be derived from parts of the Urcucocha skarn field. Six specimens were examined. The lithologies are distinct from the Urcucocha outcrop specimens already described. Four are grossular skarns with interstitial quartz. In these a late retrograde mineral assemblage of apple green hornblende, epidote, quartz, carbonate and opaque granules occurs at interstices and grain boundaries of the garnet fabric, in hairline fractures, and locally as patchy garnet alteration.

One specimen is a banded rock. The thin section shows three bands, one rich in 2-3 mm wide opaque porphyroblasts (probably of pyrite) set in granoblastic quartz-epidote-amphibole (pale blue-green actinolitic hornblende). The second band is pale and quartz-rich with epidote, amphibole and accessory titanite. The third consists of fine, granoblastic epidote and quartz with minor amphibole and accessory apatite.

The last specimen consists of a massive, coarsely intergrown hornblende and epidote, accompanied by 3-4 % of disseminated opaque grains (?magnetite) and minor amounts of quartz and apatite. In one part of the section this assemblage is accompanied also by 2-3 mm wide replacive patches of clear calcite.

Taken together with Urcucocha, the Río Quijos suite indicates a skarn field in which grandite skarn and epidote-amphibole rock are the dominant rock types, occurring in a sequence which also includes acidic metavolcanic schists.

Analyses of this group of samples have already been discussed, and do not show evidence of significant metal enrichment.

7.7 Oyacachi

Thin sections of seven specimens from blocks derived from a skarn field in the Oyacachi area were examined. Most of them are moderately metasomatized schists, but one is an epidotised breccia and another is a skarn.

The schists can be subdivided into feldspathic metavolcanic rocks and wollastonite-bearing rocks possibly derived from metamorphosed calcareous pelites. Three thin sections of feldspathic schist each display a complex pattern of metasomatic alteration. The pre-existing rock was made up of lenticles of quartz and feldspar probably interposed with micaceous laminae. The feldspar includes both orthoclase and albite. In one specimen isolated minute patches of myrmekitic intergrowth are present. Fine grained red-brown biotite has replaced much of the original micaceous laminae and also occurs as swarms of microscopic flakes grown inside feldspar crystals. The biotite is accompanied by opaque grains, rutile granules a very pale green muscovite. The biotitic alteration occurs intermingled with bands and lenses of fine-grained hedenbergite. In one of the sections hedenbergite occurs interposed with area of untwinned feldspar mosaic accompanied by minute interstitial pockets of what I interpret as prehnite. Another of the sections shows remnants of feldspathic schist among bands and lenticles of fine-grained hedenbergite and weakly birefringent grandite.

The metasedimentary schists are dominated by granoblastic quartz mosaic in which the schistose fabric is picked out by foliae of opaque, probably hematitic or carbonaceous material. These rocks contain an abundance of blocky wollastonite porphyroblasts accompanied by minor muscovite. The wollastonite crystals look deformed and slightly dismembered, sometimes being sited in small ovoid areas of clear quartz. They are probably of syn-metamorphic/syn-kinematic origin.

In the breccia, clasts of fine to medium grained semi-massive epidote-quartz rock, with minor carbonate, are set in a matrix of granoblastic quartz-carbonate mosaic. No schistose fabric was recorded, but it is possible that both brecciation and epidotisation took place during skarn alteration and thus after the regional metamorphism.

In the skarn specimen, coarse pale pink garnet crystals are interspersed with areas of quartz mosaic and areas in which fine grained hedenbergite and epidote coexist. Spongy poikilitic carbonate crystals have formed by partial replacement of all these minerals.

7.8 Sara Urco

Seven thin sections of specimens from this skarn field, sited a considerable distance NNE of the Llanganates area, were examined. All of them are skarns with the single exception of a quartz-feldspar rock with moderate clinozoisite alteration. All of the skarn specimens have a massive character in which relicts of pale pink garnet remain after a complex process of alteration. Fine grained intergrown hedenbergite and epidote are considered here to have formed to some extent after the garnet, which they are seen to partially replace. Minor quantities of fine grained ferrohastingsite and deep brown biotite or stilpnomelane are locally concentrated on trails indicating growth along fractures in the pyroxenic mosaic. Spongy, coarse carbonate crystals enclose and partially replace all the earlier formed minerals, and are the dominant component in one of the specimens. The proportion of hedenbergite to epidote varies widely. Thus, the pyroxene is effectively absent from two of the specimens, while epidote was not recorded from one.

In one of the skarn rocks (MP-615), the alteration pattern is quite different. A very coarse garnet aggregate is cut by veinlets of what may be prehnite. The next stage of alteration is marked by deposition of green biotite, actinolite and chlorite on shears which cut across the rock. Later still, carbonate was deposited extensively, along the pre-existing veinlets and by occupying additional fractures in the garnet. The garnet crystals have been intensely fractured. The rock can be interpreted in terms of intense brittle fracturing, possibly a percussive process, before being further disrupted by shearing. During this process, metasomatic alteration progressed from prehnite to biotite-actinolite. Carbonate deposition was later, exploiting the pre-existing structure and accompanied by retrograde chloritisation of the amphibole.

The remaining specimen (MP-554C) consists of a medium grained mosaic of quartz and strongly clouded albite grains, accompanied by abundant clinozoisite grains and disseminated opaque grains. Some of the latter have cuboid forms indicative of pyrite.

7.9 Discussion

As previously pointed out by Dr. Litherland in the Project Reports, variation in skarn mineralogy reflects variety in the original protolith. Moreover, as Williams observes, the skarn alteration process obliterates earlier textures, but from partially altered rocks it is apparent that the skarns formed after regional kinematic metamorphism. The protolith was a sequence of metavolcanic and metasedimentary rocks of low to medium metamorphic grade. Acidic metavolcanics are preserved as feldspathic schists, and basic varieties may be represented by actinolitic schists described by Williams from the Llanganates area. Sedimentary varieties include impure marbles at Llanganates and wollastonite-schists at Sara Urco. Within the skarns themselves, controls of the mineralogy may include temperature and redox potential as well as composition of the protolith. Variation in the permeability of the original schists could control rates of fluid movement during the metasomatism, providing an additional factor that could affect reaction rates, temperature, chemical gradients and other parameters. These considerations emphasise the degree to which skarnification must be seen as a complex process of reaction between the protolith and migrating metasomatic fluid.

Skarnification is dominated by formation of calc-silicate minerals and, more rarely, magnesium silicates and tourmaline. Fluids deficient in CO₂ and SO₂ brought about Ca, Mg and B metasomatism. In addition, local biotitic alteration indicates a degree of K metasomatism.

Local moderate molybdenite enrichment (to 5000 ppm Mo in epidote skarn from Urcucocha) is the only real confirmation of economic potential which can be seen in the present data. Texturally, the pale pink, generally isotropic garnet crystals are distinct from those in the Nambija auriferous mineralisation. Adularia is very rare. However, a degree of calcitic retrograde alteration is generally present throughout these skarns, and so there remains the possibility of currently undiscovered areas within them of metalliferous mineralisation.

Perhaps the main question posed by these skarns is the reason for their regional extent. Skarns are associated with situations in which metasomatism is concentrated by structures such as cusate intrusion-country rock contacts or fracture zones associated with high level acid-intermediate intrusions. In the present case, possible controls could be a series of small plutons, sites along the margin of a batholithic body, or sites on faulted intrusion margins developed during or soon after emplacement of the intrusion/s.

8. The Monte Olivo pegmatite belt

Four specimens (MC-643C, MC-644A, MC-644B and MC-646A) were examined in thin section. Although they collectively display pegmatoid features, notably coarse cm-scale sheaves of muscovite, they are in fact deformed gneissose granites in which original mafic silicates have been destroyed, while sericite and muscovite have become major constituents. MC-643C is notable for the occurrence of thinly scattered 1-2mm pseudo-hexagonal crystals of a deep, inky blue mineral provisionally identified as dumortierite $[Al_7BSi_3O_{18}(OH)]$, a mineral characteristically found in granite-pegmatites and hydrothermally altered granitoids (Heinrich, 1965). However, confirmation at a later stage of this identification is advised.

Specimen MC-646A is distinct in that it is albite rich, and poor in both quartz and K-feldspar. Moreover, it has suffered hydrothermal alteration to muscovite, chlorite and coarse (up to 3 mm long) euhedral prismatic epidote. This alteration becomes exclusively chloritic around a massive, outwardly poikilitic, skeletal patch of probable titanite, within which is an irregular, part digested core of golden red probable rutile. The “titanite” could be a misidentification of cassiterite, and I would advise further work to rule out this possibility and confirm the identity of the “rutile”.

Two additional specimens, MC-642A and MC-645A, are feldspathic schists. In the first, schlieren-like shreds of fine-grained feldspathic schist contain coarse porphyroblasts of orthoclase, and preserve an isoclinally contorted schistose fabric. However, much of this rock consists of a groundmass of granoblastic quartz with minor interstitial feldspar. The rock can be interpreted as semi-pelitic schist which has been strongly crenulated and feldspathised. MC-645A is similar, but here shreds of feldspathic schist have become more or less detached from one another, and are embedded in a groundmass of albite mosaic. It is thus an albite-schist. Orange ferroan material, possibly jarosite, forms local stains, cross-cutting veinlets, and local pseudomorphous patches after pyrite. These pyritic patches are accompanied by fringes of cross-fibre quartz. In their strongly feldspathic character, these two rocks may be petrogenetically related to the albitic granitoid MC-646A in that all three have undergone soda-metasomatism and feldspathisation.

8.1 Reference

HEINRICH E. W. (1965) Microscopic identification of minerals. McGraw-Hill, New York, 414 pp.

APPENDIX 5

Palaeontological reports (5a-5c)

BRITISH GEOLOGICAL SURVEY
Natural Environment Research Council

TECHNICAL REPORT
Stratigraphy Series

Biostratigraphy Research Group
Stratigraphy & Tectonics Group Report

Keyworth, Nottinghamshire British Geological Survey

APPENDIX 5a

**A palynological investigation of nine rock samples from Ecuador
(Maguazo subdivision – Cuenca to Paute road)**

Report WH/89/361R - PD/89/333

Geographical index

Ecuador

Subject index

Palynomorphs

Biostratigraphy

Copies to: 1. Dr. J. Aspden.
 2. Dr. J. D. Bennett
 3. Dr. B. Owens
 4. Biostratigraphy Research Group Files

Samples submitted by : J. A. Aspden/J. D. Bennett
 Samples prepared by : K. L. Kirby
 Samples examined by : J. B. Riding

1. Introduction

Nine rock samples from Ecuador were submitted for palynological analyses in order to attempt detailed age determinations. No geographical co-ordinates were supplied; the lithologies of the samples were largely black/grey phyllites.

2. Sample details

No.	BRG Registration No.	Collection No.	Result +/-
1	MPA-30725	A-P-01	+
2	MPA-30726	A-P-02	+
3	MPA-30727	A-P-03	-
4	MPA-30728	A-P-04	-
5	MPA-30729	A-P-05	+
6	MPA-30730	A-P-06	-
7	MPA-30731	A-P-07	+
8	MPA-30732	A-P-08	-
9	MPA-30733	TAMPANCHI-01	-

3. Palynostratigraphy

Table 1 lists all the palynomorphs identified in the course of this investigation.

The samples yielded very sparse associations of palynomorphs with numbers 3, 4, 6, 8 and 9 being entirely barren. The indeterminate and non-age diagnostic nature of the palynofloras in samples 5 and 7 respectively means that age determinations are not possible on these horizons.

The pollen florules in samples 1 and 2 are indicative of a broad Jurassic/Cretaceous age. *Perinopollenites elatoides* is confined to the latter systems and *Classopollis classoides* is typically Mesozoic. The presence of the dinoflagellate cyst *Sirmiodinium grossii* in sample 1 is indicative of a Mid Jurassic (uppermost Bathonian) to Early Cretaceous (late Barremian) age, if the single specimen recovered is in situ. Two palynomorphs, tentatively assigned to “?acritarch indet” were also recovered from sample 1. The preservation and level of organic maturity are significantly different to the remainder of the florule. These forms may represent the reworking of ?Lower Palaeozoic material, similar to the situation found in a sample from the Maguazo Division, Río Jadán, Ecuador (see WH/88/347R).

The dark nature of the kerogen macerals is suggestive of a relatively high thermal alteration index

.

Table 1. List of palynomorphs recovered

1. A-P-01
Pteridophyte spores – indet
pollen – indet
<i>Perinopollenites elatoides</i> (pollen)
<i>Sirmiodinium grossii</i> (dinoflagellate cyst)
acritarch? – indet
2. A-P-02
<i>Classopollis classoides</i> (pollen)
<i>Perinopollenites elatoides</i> ?
5. AP-05
pollen – indet
7. A-P-07
bisaccate pollen

J. B. Riding
6 October 1989

APPENDIX 5b

**A palynological investigation of six rock samples from Ecuador
(Chigüinda subdivision)**

Report WH/89/354R - PD/89/326

Geographical index

Ecuador

Subject index

Palynomorphs

Biostratigraphy

Mesozoic

Copies to: 1. Dr. J. Aspden.
 2. Dr. J. D. Bennett
 3. Dr. B. Owens
 4. Biostratigraphy Research Group Files

Samples submitted by : J. A. Aspden

Samples prepared by : K. L. Kirby

Samples examined by : J. B. Riding

1. Introduction

Six rock samples from Ecuador were submitted for palynological analyses in order to attempt detailed age assessments. No geographical co-ordinates of the locality(s) sampled were given, the lithologies were chiefly dark grey/black phyllites.

2. Sample details

No.	BRG Registration No	Collection No.	Result +/-
1	MPA-311171	CR-FV-733	-
2	MPA-311172	CR-FV-739	+
3	MPA-311173	CR-FV-746	-
4	MPA-311174	CR-FV-863A	+
5	MPA-311175	CR-FV-863B	+
6	MPA-311176	L.D1	+

3. Palynostratigraphy

All samples yielded sparse acid-resistant residues which were relatively rich in residual mineral grains with lesser proportions of dark woody tissue. Palynomorphs proved extremely rare, samples 1 and 3 being entirely devoid of sporopollenin microfossils. Table 1 lists the palynofloras recovered from samples 2, 4, 5 and 6.

Because of the indeterminate nature of the palynofloras in samples 2 and 5, no comment can be made on the age of these horizons. The occurrence of *Perinopollenites elatoides* in sample 4 is suggestive of the Jurassic/Cretaceous interval. It is a relatively long-ranging taxon from the Early Jurassic to the Cretaceous; its precise range top is not known.

The single spore in sample 6 was tentatively identified as *Uvaesporites* sp. This genus is well represented from the Mid Jurassic to Early Cretaceous of Europe, thus this spore suggests a Mesozoic age for L.D1.

In conclusion, therefore, the very limited evidence from samples 4 and 6 is suggestive of a broad Jurassic/Cretaceous age, providing the specimens recovered are indigenous.

No marine microplankton was recovered and the nature of the kerogen assemblages indicates a relatively high level of thermal maturation.

Table 1. List of palynomorphs recovered

2. CR-FV-739
Pteridophyte spores– indeterminate
4. CR-FV-863A
? <i>Cyathidites</i> sp. (spore)
<i>Perinopollenites elatoides</i> (pollen)
5. CR-FV-863B
pollen grain – indeterminate
6. L.D1
pollen grains – indeterminate
? <i>Uvaesporites</i> sp. (spore)

J. B. Riding
3 October 1989

APPENDIX 5c

Report on fossil fish from Laguna de Atillo, Ecuador

Report WH/90/54R - PD 90/50

Geographical index

Ecuador

Subject index

Pisces

Tertiary

Biostratigraphy

The single specimen (CR-FV-855) is the front half of a teleost fish preserved as a carbonaceous or bituminous film, presumably through post-depositional “cooking”. The head and dentition are reasonably well preserved and are enough to identify the fish as a member of the subfamily Characinae of the family Characidae (order Characiformes). Characiforms are exclusively freshwater and characins are endemic to South America. The Characinae are a very large group including about 150 living genera and almost 700 living species. Since the fossil is incomplete and also appears to lack scales and most of the fins (through post-mortem damage), it is very unlikely that it could be assigned to a genus with any confidence. “Cf. Brycon” is the furthest my colleague Gordon Howes (who has reviewed that genus, Howes, 1982) would go.

Although characins dominate the rivers and lakes of South America, they are surprisingly rare as fossils. The fossil record of characiforms is reviewed by Weitzman (1960a, b) and Gayet (1982). The currently accepted stratigraphic range of characins in South America is Maestrichtian (Gayet, 1982; Marshall et al., 1985) to Pleistocene. However, the age of the supposedly Maestrichtian deposits (which include the oldest known mammals from South America) has been questioned by Van Valen (1988), who infers that they are early Palaeocene; I would agree. In Ecuador, six taxa of characiforms have been described from the Miocene Loyola and Mangán Formations in the Cuenca Basin, to the south of the present locality (Bristow, 1973; Roberts, 1975). Apart from one “nearly complete” fish recorded by Bristow (1973: 27) as “cf. Moenkhausia” (a small characin, identification by P.H. Greenwood, BM(NH)), all are based on isolated teeth. The teeth of the present specimen are similar to those illustrated by Roberts (1975: fig.2) as “cf. Tetragonopterinae”, but these multicuspid teeth are probably primitive for characiforms as a whole (Fink & Fink, 1981: 306), and Tetragonopterinae is merely a name for primitive characins.

In summary, the most that one could say from the present specimen is that the deposit is freshwater, and that the age is Tertiary.

REFERENCES

- BRISTOW C. R. (1973)** Guide to the geology of the Cuenca Basin, southern Ecuador. Quito: Ecuadorian Geological and Geophysical Society.
- FINK S. V. and FINK W. L. (1981)** Interrelationships of the ostariophysan fishes (Teleostei). Zool. J. Linn. Soc. London. 72: 297-353.
- GAYET M. (1982)** Découverte dans le Crétacé de Bolivie des plus anciens Characiformes connus. C. r. Acad. Sci. Paris (11). 294: 1037-1040.
- HOWES G. J. (1982)** Review of the genus Brycon. Bull. Br. Mus. Nat. Hist. (Zool.). 43: 1-47.
- MARSHALL L. G., DE MUIZON C., GAYET M., LAVENU A. and SIGÉ B. (1985)** The "Rosetta Stone" for mammalian evolution in South America. Nat. Geogr. Res. 1: 274-288.
- ROBERTS T. R. (1975)** Characoid fish teeth from Miocene deposits in the Cuenca Basin, Ecuador. J. Zool., Lond. 175: 259-271.
- VAN VALEN L. M. (1988)** Paleocene dinosaurs or Cretaceous ungulates in South America? Evolut. Monogr. 10:1-79.
- WEITZMAN S. H. (1960a)** The systematic position of Piton's presumed characid fishes from the Eocene of central France. Stanf. Ichthyol. Bull. 7: 114-123.
- WEITZMAN S. H. (1960b)** Further notes on characid fossils. Stanf. Ichthyol. Bull. 7: 215-216.

Colin Patterson
British Museum (Natural History), London SW7 5BD.
19 January 1990

APPENDIX 6

Geochemical studies stream sediment/rock analyses

(6a-6b)

(INEMIN, ACME and Caleb-Brett)

Appendix 6a

Location and brief descriptions of mineralised rock samples

553-K: Mineralised block of ?metalava, Sara Urco (1717-99888)

553-L.1: Mineralised block with pyrite, Sara Urco (1717-99888)

607-B: Pyritic Napo Fm., Río Cascabel, west bank tributary of Río Salado (Map 7, in Litherland, 1989)

609-B: Mineralised (pyrite) porphyry outcrop, Río Salado (Map 7, in Litherland, 1989)

A-169: Kaolinised ?Tres Lagunas granite with minor galena (Map 3, Oñacapa to Yacuambí traverse)

MC-630: ?Metabasalt outcrop, Río Blanco de Patate

MC-635: Calc-arenite float, Río Blanco de Patate

MC-637: Magnetite skarn float, Río Verde (7990-98467)

MC-638: Magnetite-epidote skarn outcrop, Río Verde skarnfield (7990-98467)

MC-639: Magnetite epidote skarn outcrop, Río Verde skarnfield (7990-98467).

Fourth Annual Report (1989-1990)

INSTITUTO ECUATORIANO DE MINERÍA

DEPARTAMENTO DE LABORATORIOS

CHEMICAL ANALYSIS REPORT

LAB N°: 4004

DELIVERY: Ing. Iván Endara

DATE: 89-05-05

N° of SAMPLES: Four

Jefe de Laboratorios

REQUESTED BY: Ing. Miguel Pozo

RECEPTION: Ing. Marco Marín

DATE: 89-05-08

PROJECT: Cordillera Real

Director de investigación geológica

ORIGIN: Napo-Sara Urco

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Co (ppm)	Cu (ppm)	Ag (ppm)	Ni (ppm)	Au (ppm)	Mo (ppm)	As (ppm)
553-K	452	238	97	18	10	66	Nd	Nd	100
553-L.1	1183	176	78	773	13	1736	0.2	Nd	105
607-B	119	101	55	13	6	104	Nd	25	165
609-B	236	121	31	80	8	610	Nd	20	160

Nd = Not detectable, less than 0.1 ppm Au and 16 ppm Mo

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.

Jefe de Determinaciones Analíticas

INSTITUTO ECUATORIANO DE MINERÍA

DEPARTAMENTO DE LABORATORIOS

CHEMICAL ANALYSIS REPORT

LAB N°: 4030 DELIVERY: Ing. Iván Endara DATE: 89-06-29
 N° of SAMPLES: Five Jefe de Laboratorios
 REQUESTED BY: Ing. Francisco Viteri RECEPTION: Ing. Marco Marín DATE: 89-06-30
 PROJECT: Cordillera Real Director de investigación geológica
 ORIGIN: Las Juntas-Loja, See Map 3 for the location of the samples

DETERMINATIONS

SAMPLE CODE	Zn (ppm)	Pb (ppm)	Cu (ppm)	Ag (ppm)	Ni (ppm)	Cr (ppm)	W (ppm)	Sn (ppm)	As (ppm)	Mo (ppm)
A-254-F	56	64	15	7	Nd	9	Nd		30	Nd
A-256-F	49	85	18	1	Nd	12	Nd		30	Nd
A-257-F	45	101	20	3	Nd	34	Nd		48	Nd
A-262-F	60	107	28	1	Nd	8	Nd		22	Nd
A-169-R*	68	134	6	1	Nd	Nd	Nd	Nd	46	Nd

Nd = Not detectable, less than 6 ppm Ni and Cr, 16 ppm Sn, W and Mo

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.
 Jefe de Determinaciones Analíticas

NOTE: 254-262 are stream sediments; 169 is rock

* Kaolinized granite –Tres Lagunas subdivision

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INSTITUTO ECUATORIANO DE MINERÍA

DEPARTAMENTO DE LABORATORIOS

CHEMICAL ANALYSIS REPORT

LAB N°: 4066

DELIVERY: Ing. Iván Endara

DATE: 89-08-17

N° of SAMPLES: Seventeen

Jefe de Laboratorios

REQUESTED BY: Ing. Francisco Viteri

RECEPTION: Ing. Marco Marín

DATE: 89-08-28

PROJECT: Cordillera Real

Director de investigación geológica

ORIGIN: Various, See Map 4 for the location of the samples

DETERMINATIONS

SAMPLE CODE	MnO (%)	TiO ₂ (%)	Fe ₂ O ₃ (%)	Al ₂ O ₃ (%)	Zn (ppm)	Pb (ppm)	Co (ppm)	V (ppm)	Cu (ppm)	Ag (ppm)	Ni (ppm)	Cr (ppm)
A-263-F	0.08	0.87	8.88	13.59	76	157	44	189	90	4	49	24
A-268-F	0.03	0.44	1.57	4.48	27	17	5	17	7	Nd	27	Nd
A-271-F	0.06	0.79	6.25	11.77	145	107	27	131	39	Nd	42	28
A-272-F	0.05	0.81	5.55	12.18	147	107	29	110	43	5	71	51
A-275-F	0.05	1.43	3.83	6.96	65	70	23	21	28	6	81	41
A-277-F	0.06	0.69	5.93	14.34	136	132	26	108	63	5	48	25
A-279-A	0.10	1.08	16.37	12.53	78	143	42	301	50	9	61	50
A-279-B	0.10	1.10	18.03	12.43	98	153	46	351	42	12	68	62
A-279-C	0.10	1.07	16.10	12.49	75	150	46	368	49	7	65	43
A-279-D	0.09	0.99	15.02	12.24	85	166	50	328	50	10	72	54
A-279-E	0.10	0.87	9.53	14.64	88	144	32	207	55	1	62	Nd
A-279-F	0.09	0.85	9.67	14.41	86	132	36	232	56	Nd	36	Nd
A-279-G	0.09	0.87	10.21	13.58	100	136	38	221	69	1	67	Nd
A-279-H	0.09	0.80	9.17	12.72	87	132	37	215	57	1	47	4
A-279-I	0.10	1.08	14.51	14.37	80	137	37	277	45	1	44	10
A-279-J	0.10	1.02	14.44	13.39	79	138	40	307	49	2	56	15
A-279-K	0.10	1.06	15.15	13.41	74	144	40	320	52	2	47	12

Nd = no detectable, less than 1 ppm Ag and Cr

ASSAYED BY: Determinaciones Analíticas

MARIANA LÓPEZ

Jefe de Determinaciones Analíticas

Note: As results will be reported subsequently

A279A-K duplicate samples from Río Chicaña

INSTITUTO ECUATORIANO DE MINERÍA
DEPARTAMENTO DE LABORATORIOS
CHEMICAL ANALYSIS REPORT

LAB N°: 4066	DELIVERY:	Ing. Iván Endara	DATE: 89-08-31
N° of SAMPLES: Seventeen		Jefe de Laboratorios	
REQUESTED BY: Ing. Francisco Viteri	RECEPTION:	Ing. Marco Marín	DATE: 89-09-04
PROJECT: Cordillera Real		Director de investigación geológica	
ORIGIN: Various, See Map 4 for the location of the samples			

SAMPLE CODE	As (ppm)
A-263-F	170
A-268-F	145
A-271-F	180
A-272-F	145
A-275-F	145
A-277-F	150
A-279-A	120
A-279-B	105
A-279-C	120
A-279-D	100
A-279-E	100
A-279-F	160
A-279-G	120
A-279-H	125
A-279-I	100
A-279-J	95
A-279-K	120

SUSANA R.
Jefe de Determinaciones Analíticas

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INSTITUTO ECUATORIANO DE MINERÍA

DEPARTAMENTO DE LABORATORIOS

CHEMICAL ANALYSIS REPORT

LAB N°: 4097

DELIVERY: Ing. Iván Endara

DATE: 89-11-01

N° of SAMPLES: Five (rocks)

Jefe de Laboratorios

REQUESTED BY: Dr. Martin Litherland

RECEPTION: Ing. Marco Marín

DATE: 89-11-06

PROJECT: Cordillera Real

Director de investigación geológica

ORIGIN: Various

DETERMINATIONS

SAMPLE CODE	Au (ppm)	Zn (ppm)	Ag (ppm)	Pb (ppm)	Co (ppm)	Ni (ppm)	Cu (ppm)	Fe (%)
MC-630	Nd	100	Nd	58	56	176	150	4.66
MC-635	Nd	56	Nd	76	40	300	20	2.10
MC-637	Nd	154	Nd	82	112	334	26	19.95
MC-638	Nd	116	Nd	98	48	362	24	7.46
MC-639	Nd	114	Nd	76	42	280	16	3.04

Nd = Not detectable, less than 1 ppm Ag, 0.1 ppm Au

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.

Jefe de Determinaciones Analíticas

NOTE: Mo and Cr results, requested from this lab, will be reported subsequently.

INSTITUTO ECUATORIANO DE MINERÍA

DEPARTAMENTO DE LABORATORIOS

CHEMICAL ANALYSIS REPORT

LAB N°: 4177

DELIVERY: Ing. Iván Endara

DATE: 90-03-01

N° of SAMPLES: Twenty

Jefe de Laboratorios

REQUESTED BY: Ing. Ramiro Bermúdez

RECEPTION: Ing. Marco Marín

DATE: 90-03-02

PROJECT: Cordillera Real

Director de investigación geológica

ORIGIN: CR-RB-191F-195F (Río Tutanangoza-Río Ojal, See Map 7); CR-ML-136F-150F (Río Cofanes and Río Chingual zone, see Map 2)

DETERMINATIONS

SAMPLE CODE	Ag (ppm)	Pb (ppm)	Cu (ppm)	Co (ppm)	Ni (ppm)
CR-RB-191-F	Nd	66	74	44	80
CR-RB-192-F	Nd	60	84	52	98
CR-RB-193-F	Nd	78	106	50	78
CR-RB-194-F	Nd	58	54	42	64
CR-RB-195-F	Nd	52	70	48	80
CR-ML-136-F	Nd	52	32	46	76
CR-ML-137-F	Nd	66	40	40	66
CR-ML-138-F	Nd	44	44	40	52
CR-ML-139-F	Nd	46	36	38	60
CR-ML-140-F	Nd	50	30	48	94
CR-ML-141-F	Nd	96	40	46	96
CR-ML-142-F	Nd	50	36	42	70
CR-ML-143-F	Nd	52	68	50	80
CR-ML-144-F	Nd	42	42	44	68
CR-ML-145-F	Nd	58	44	44	78
CR-ML-146-F	Nd	60	68	48	78
CR-ML-147-F	Nd	76	76	44	60
CR-ML-148-F	Nd	54	68	46	52
CR-ML-149-F	Nd	48	38	34	60
CR-ML-150-F	Nd	56	48	38	60

Nd = Not detectable, less than 2 ppm Ag

ASSAYED BY: Determinaciones Analíticas

SUSANA SALVADOR A.

Jefe de Determinaciones Analíticas

NOTE: Due to force majeure, the results for As, Zn, V, Mo, Cr, and W cannot be reported at this time.

Appendix 6b

Location and brief descriptions of mineralised rock samples

CR-FV-908: Sulphide-bearing quartz vein outcrop in Tres Lagunas subdivision on track from Alao to El Placer (7859-98036)

CR-RB-180A: Pegmatite float block Río Blanco near Pimampiro (1739-00367)

CR-MP-462B/C: Garnet granite float near Oyacachi (8280-99762)

CR-MP-462D: Garnet granite float near Oyacachi (8280-99762)

CR-MC-640B: Magnesite-veined, sheared serpentinite band (10 cm) with fuchsite. 100 m west of Río El Carmen bridge near Monte Olivo (1814-00435)

CR-MC-642B: Float block of gneiss with magnetite, Río Minas near San Gabriel

CR-MC-643B: Tourmaline pegmatite float, Quebrada Juan Ibarra, Río Minas

CR-MC-644C: Pegmatite/greisen float, Quebrada Juan Ibarra, Río Minas

CR-MC-644G: Pegmatite float, Quebrada Juan Ibarra, Río Minas

CR-MC-645B: Mineralised block quartzite outcrop near Ambuquí (1663-00492)

CR-MC-652B: Pegmatite with magnetite from Condué granite, float in Río San Jorge (1958 00415)

CR-MC-653A: Muscovite gneiss with disseminated Cu-mineralisation, float from Río Condué (1960-00415)

CR-FV-757A: Silicified ?porphyry float with disseminated sulphides from Río Cambana (7350-95983)

CR-FV-770: Float of ?silicified and epidotised volcanic with sulphides, Río Cantzama (7305-95739)

M-659-A: Serpentinite float, Río Cofanes (2064-00425)

M-659-B: Serpentinite float, Río Cofanes (2064-00425)

M-659-E: Float of hornfelsed banded siliceous rock with garnet, Río Cofanes (2064-00425)

M-659-F: Mylonitic ?granodiorite with pyrite/chalcopyrite, float Río Cofanes (2064-00425)

M-660-B: Sheared greenstone float, Quebrada Pilares (2037-00362).

M-662: Mineralised mylonite granodiorite float, Quebrada La Dantina near La Bonita (2169-00505)

M-666A: Mineralised epidotised greenstone float, Río Palmar near Rosa Florida (2182-00460)

M-666B: Mineralised, fine grained, banded ?tuff with garnet (?hornfels). Float from Río Palmar near Rosa Florida (2182 00460)

M-667B: Mineralised fine grained volcanic float, Quebrada La Industria near Rosa Florida (2181-00454)

M-667C: Mineralised (Zn-Cu) 2 cm layer in banded, fine grained, siliceous hornfels, Quebrada La Industria near Rosa Florida (2181-00454)

M-667D: Epidote-rich (?skarn) float, Quebrada La Industria near Rosa Florida (2181-00454)

M-668: 10 cm pyrite/chalcopyrite/epidote vein in quartz monzonite pluton Quebrada Las Juntas near Rosa Florida (2181-00446)

M-677: Serpentinite float, Río Huagracyacu near Baeza (8425-99477)

RB-159A: Napo Fm., oolitic limestone outcrop, Río Mulatos

MP-462B: Garnet granite float, Río Oyacachi (8280-99762)

CR-MP-553B: Calcic skarn block, Sara Urco (1717-99888)

MP-553D.1: Pyritic skarn block, Sara Urco (1717-99888)

CR-MP-553D.2: Magnetite-rich block, Sara Urco (1717-99888)

MP-554C: Mineralised garnet calc-silicate block, Sara Urco (1725-99888)

MP-554F: Calcic skarn block, Sara Urco (1725-99888)

MP-609: Mineralised (pyrite) porphyry outcrop related to Azafrán intrusive phase, Río Salado (Map 7, in Litherland, 1989)

MP-617: Skarn block, Río Diviso, tributary of Río Salado (Map 7, in Litherland, 1989)

CR-HL-677: Pyrite, chalcopyrite and sphalerite mineralised float from Río Quijos, Papallacta-Baeza road.

ANALYSES FROM CALEB - BRETT ST. HELENS, U.K. (GREENWICH RESOURCES)

SAMPLE	Ag (ppm)	As (ppm)	Bi (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mo (ppm)	Ni (ppm)	Pb (ppm)	Sb (ppm)	Sn (ppm)	Th (ppm)	U (ppm)	V (ppm)	W (ppm)	Zn (ppm)
CR-FV-908	5	<20	<1	<2	12	123	51	4.11	<5	15	3170	<20	<1	38	2	47	<1	42
CR-RB-180-A	<1	<20	<1	<2	<5	189	7	0.48	<5	<5	62	<20	<1	<1	7	7	<1	8
CR-MP-462-B/C	<1	<20	<1	<2	24	313	41	7.66	7	41	19	<20	2	27	4	244	2	100
CR-MP-462-D	<1	<20	<1	<2	10	278	10	2.06	<5	14	31	<20	1	11	3	47	3	48
CR-MC-640-B	<1	167	<1	<2	44	1410	10	3.04	<5	665	15	<20	3	2	<1	29	<1	173
CR-MC-642-B	<1	<20	<1	<2	15	244	13	4.48	<5	37	35	<20	17	<1	4	103	<1	248
CR-MC-643-B	<1	<20	<1	<2	<5	239	2	0.53	<5	7	15	<20	33	<1	13	3	<1	81
CR-MC-644-G	<1	<20	<1	<2	<5	363	7	1.14	<5	9	25	<20	11	<1	8	4	3	288
CR-MC-644-C	<1	<20	<1	<2	<5	254	3	0.38	<5	6	9	<20	3	13	4	3	<1	80
CR-MC-645-B	<1	<20	<1	<2	<5	469	10	1.71	<5	9	30	<20	<1	4	2	22	1	236
CR-MC-652-B	<1	<20	<1	<2	<5	347	32	1.85	<5	6	29	<20	<1	2	3	33	2	478
CR-MC-653-A	1	<20	<1	<2	<5	286	1510	1.66	<5	5	18	<20	<1	3	19	28	3	332
CR-FV-757-A	<1	<20	<1	<2	24	148	10	5.78	7	5	8	<20	2	5	3	242	5	47
CR-FV-770	<1	<20	<1	6	24	74	55	8.56	<5	7	38	32	4	1	<1	300	<1	633

Cordillera Real Geological Research Project

ACME ANALYTICAL LABORATORIES LTD. 852 E. HASTINGS ST. VANCOUVER B. C. V6A 186 PHONE (604)253-3158 FAX (604)253-1716

GEOCHEMICAL ANALYSIS CERTIFICATE

DATE RECEIVED: FEB 20 1990 DATE REPORT MAILED: MARCH 01 1990 SIGNED BY: DEAN TOYE, C. LEONG, J. WANG CERTIFIED B.C. ASSAYERS

Río Tinto España - Ecuador File # 90-0453
Box 21-128 Calle Hugo Moncayo 527 y Sarmiento, Quito-Ecuador-South America Submitted by: EDGAR SALAZAR
ASSAY RECOMMENDED FOR: Cu, Pb, Zn, As >1%, Ag > 30 ppm

SAMPLE	Mo (ppm)	Cu (ppm)	Pb (ppm)	Zn (ppm)	Ag (ppm)	Ni (ppm)	Co (ppm)	Mn (ppm)	Fe (%)	As (ppm)	U (ppm)	Au (ppm)	Th (ppm)	Sr (ppm)	Cd (ppm)	Sb (ppm)	Bi (ppm)	V (ppm)	Ca (%)	P (%)	La (ppm)	Cr (ppm)	Mg (%)	Ba (ppm)	Ti (%)	B (ppm)	Al (%)	Na (%)	K (%)	W (ppm)	Au** (ppb)
M-659-A	1	33	28	44	0.4	1549	78	515	4.44	84	5	ND	1	43	1	11	2	30	0.97	0.006	2	2216	11.19	3	0.01	3	0.65	0.01	0.01	1	4
M-659-B	1	17	46	41	0.4	1083	54	379	2.94	8	5	ND	1	1	1	10	2	13	0.02	0.005	2	670	12.81	1	0.01	6	0.45	0.01	0.01	1	15
M-659-E	2	5	14	41	0.1	27	2	308	0.63	2	5	ND	3	18	2	2	2	29	2.80	0.074	6	56	0.29	11	0.04	2	0.67	0.02	0.01	1	5
M-659-F	29	269	3	139	0.3	70	13	252	2.45	3	5	ND	1	8	3	2	2	86	0.77	0.059	2	48	0.57	24	0.13	2	0.60	0.05	0.15	1	39
M-660-B	1	41	5	53	0.1	23	18	452	4.13	4	5	ND	1	18	1	2	2	79	1.78	0.123	4	71	1.66	7	0.23	2	1.63	0.07	0.09	1	7
M-662	1	48	13	84	0.1	15	22	513	3.26	2	5	ND	1	7	1	2	2	62	0.59	0.074	2	49	1.67	441	0.26	2	1.91	0.05	1.08	2	6
M-666-A	1	23	16	18	0.1	32	21	362	2.33	6	5	ND	1	33	1	2	2	45	4.73	0.244	2	70	0.37	4	0.10	3	1.00	0.01	0.01	1	8
M-666-B	1	16	19	84	0.1	31	4	258	0.96	20	5	ND	2	169	1	7	2	34	14.69	0.111	9	20	0.17	76	0.08	103	2.91	0.01	0.09	1	7
M-667-B	1	13	34	97	0.1	15	9	349	1.70	12	5	ND	3	68	1	2	3	31	1.33	0.100	11	26	0.18	27	0.15	4	0.48	0.04	0.14	1	3
M-667-C	24	692	25	38748	2.0	64	79	537	11.07	80	5	ND	2	140	494	22	3	30	13.14	0.186	19	32	0.21	2	0.09	521	1.89	0.01	0.01	1	14
M-667-D	3	43	21	244	0.6	18	6	1286	5.82	8	5	ND	1	234	3	2	2	63	7.91	0.003	2	49	0.21	5	0.13	5	2.16	0.01	0.01	2	4
M-668	7	1308	9	1211	0.5	27	7	196	2.83	7	6	ND	12	31	17	2	2	15	0.73	0.031	5	19	0.31	19	0.06	18	0.62	0.02	0.16	1	14
M-677	1	30	2	74	0.3	1613	79	394	3.89	56	5	ND	1	12	2	4	4	11	0.30	0.009	2	971	16.12	5	0.01	10	0.27	0.01	0.01	1	9
RB-159-A	1	11	37	110	0.1	12	9	2996	2.38	4	5	ND	4	184	11	2	2	21	29.63	0.039	6	12	0.61	58	0.01	3	1.18	0.03	0.06	1	2
MP-462-B	3	20	7	96	0.1	20	10	123	2.77	2	5	ND	16	12	1	2	2	27	0.39	0.021	33	23	0.82	42	0.01	2	1.72	0.08	0.15	1	8
CR-MP-553-B	1	2	4	18	0.1	3	1	1823	0.94	2	5	ND	1	59	1	2	2	12	13.65	0.001	2	5	0.04	11	0.07	2	0.71	0.01	0.02	1	5
MP-553-D.1	1	357	18	113	0.3	10	35	4609	6.85	16	5	ND	1	141	1	2	3	23	13.20	0.077	2	8	0.53	57	0.06	2	1.76	0.02	0.14	1	18
CR-MP-553-D.2	1	234	5	591	0.5	6	59	1649	45.48	28	5	ND	3	7	3	2	13	8	2.42	0.009	2	6	0.01	6	0.01	2	0.29	0.01	0.02	1	4
MP-554-C	556	85	16	75	0.1	277	15	525	4.25	5	5	ND	3	83	1	2	2	143	4.75	0.348	19	38	0.25	49	0.13	2	1.10	0.02	0.03	4	6
MP-554-F	26	146	4	45	0.1	84	17	1354	3.54	7	5	ND	30	35	1	2	2	37	1.95	0.131	5	17	0.06	9	0.08	2	0.71	0.01	0.02	1	29
MP-609	7	109	17	515	0.1	8	9	234	3.01	3	5	ND	6	9	1	2	2	38	0.29	0.017	3	6	1.24	60	0.09	2	1.11	0.03	0.13	1	8
MP-617	1	8	2	12	0.1	2	7	1532	5.97	9	5	ND	7	21	1	2	2	37	9.51	0.041	2	2	0.05	3	0.04	5	0.22	0.01	0.01	7	2
STD C/AU-R	19	63	41	132	6.6	73	30	1024	3.85	39	18	7	37	52	19	14	21	60	0.52	0.088	39	56	0.89	180	0.07	33	1.91	0.06	0.14	12	528
CR-HL-677	8	120	64	7593	2.8	227	13	999	24.54	2	5	ND	1	61	110	4	6	70	3.62	0.087	3	44	0.76	21	0.01	4	1.78	0.02	0.09	3	491
STD C/AU	18	57	42	131	6.8	67	30	949	3.97	44	20	7	37	47	19	15	23	57	0.45	0.093	37	55	0.81	175	0.06	38	1.77	0.06	0.14	11	510

APPENDIX 7

Semi-quantitative study of heavy mineral concentrates and
preliminary XRF results (7a-7b)

Ramiro Bermúdez and M. Arauz

English translation by Stalyn Paucar (2026)



No. 03179

APPENDIX 7a

QUITO, APRIL 20, 1990

TO : GERENTE TÉCNICO

FROM : ING. RAMIRO BERMÚDEZ A.

SUBJECT : Results of the semi-quantitative polymineral study of heavy sediments from the Cordillera Real Project.

1. PROJECT CONTEXT

The Technical Assistance Mission of Great Britain-INEMIN, within its work programming during the period 1986-1990, collected around 320 heavy sediment samples which were taken in the different geotraverses carried out in the Cordillera Real.

It is worth noting that prior to the study I completed an internship in the laboratories of the Geological Survey of Great Britain and Scotland, during which I became familiar with the techniques of preparation and identification of heavy minerals, especially economic minerals, for which I used sophisticated equipment such as: magnets, binocular magnifying glass, ultraviolet lamp, microchemical, etc.

Thus, the Institute's laboratories located in Sta. Bárbara No. 2 Chillogallo, especially the area in charge of mineralometric studies, have the basic material to carry out this type of study, especially regarding the preparation of the concentrate prior to its identification.

My recognition: to Mr. Guillermo Erazo, who collaborated in the preparation of the samples; to Dr. M. Litherland, Leader of the Mission, who decidedly provided his support to this mini-project of investigation.

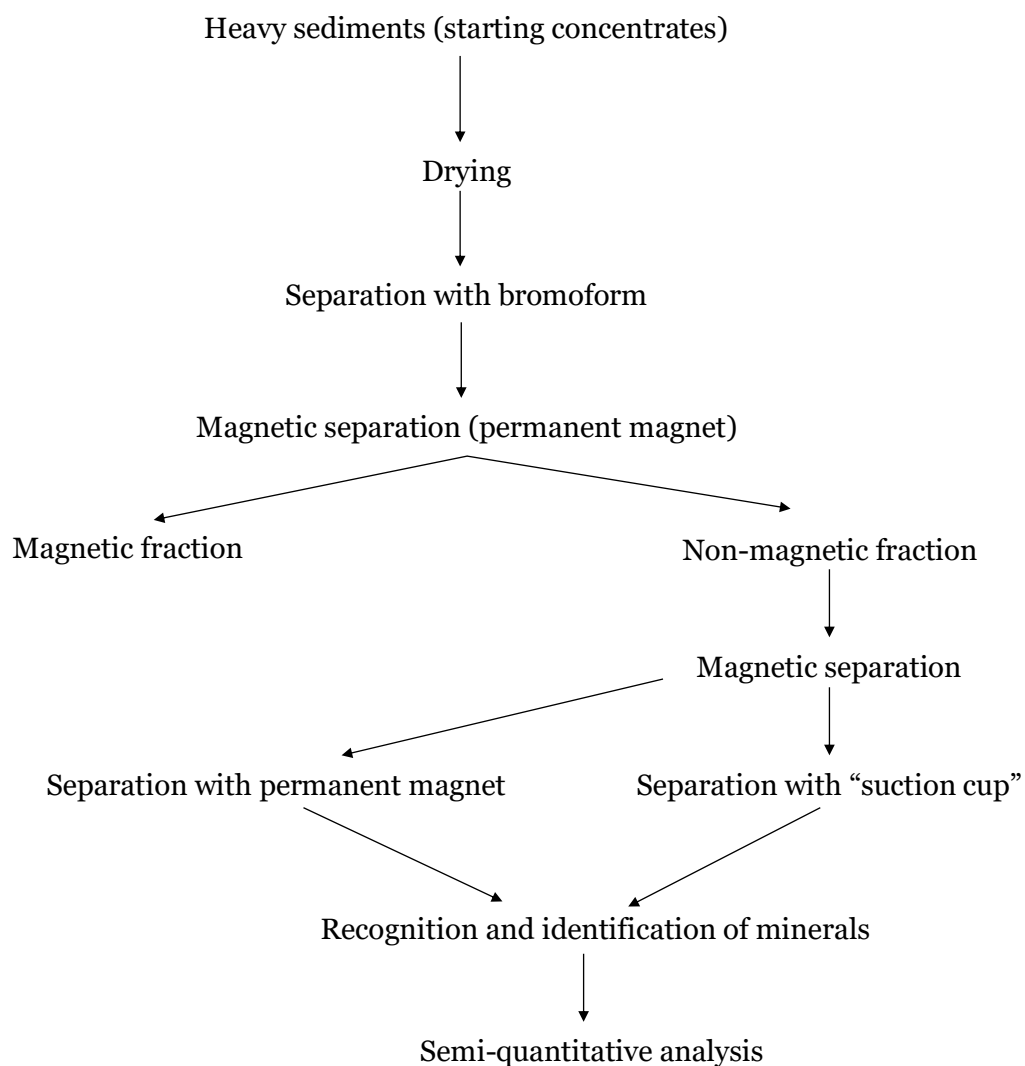
The present report is a small contribution to the great objective pursued by this project: the determination of the mineralogical potential of the Cordillera Real.

2. OBJECTIVE

Carry out the semi-quantitative polymineral study of 273 sediment samples belonging to the project.

3. METHODOLOGY

It can be summarized in the following chart:



Of the 273 samples studied, 60% were separated using bromoform. The methodology is not rigid, but in general the previously outlined scheme has been maintained.



4. RESULTS

In the tables (Appendix 7a) you can find each of the studied samples and their semi-quantitative assessment; as well as in the maps (10 and 11) their location. Simultaneously, a qualitative-chemical analysis was carried out by X-ray fluorescence (XRF) of 106 samples in the laboratories of the Escuela Politécnica Nacional (Appendix 7b).

Below, a brief mineralogical interpretation is presented:

4.1 Scheelite (WO_4Ca)

It was easily detected in the non-magnetic fraction using ultraviolet light. Its most noticeable presence is in samples belonging to the Oyacachi sector, which could be related to contact metamorphism-skarn samples?

4.2 Zircon (SiO_4Zr)

It appears in the form of bipyramidal, crystalline prisms of varied colour. Easily detected in the non-magnetic fraction providing a yellow fluorescence under the light.

Zircon is present in all the samples studied, except for 43.

Its conspicuous presence may be related to granitoid terrains in general.

4.3 Gold (Au)

It appears in the form of flattened, laminar grains of yellow colour with metallic lustre.

There are only 50 samples with gold, of which 19 present more than 5 grains combined with coarse grains and laminar gold.

The highest content achieved in one sample was 14 small and laminar grains belonging to a sample from the Numbala River.

4.4 Wolframite (Wo_4FeMn)

It appears in prismatic, tabular form, with submetallic lustre and grey to black colour.

There are very few samples with the presence of this mineral and its content is very low.

4.5 Cassiterite (SnO_2)

It is present (?) in very few samples and its content is very low; having performed the test for its identification, the chemical phenomenon is not 100% present. It seems that the variety we would have is of dark colours, almost metallic lustre.

4.6 Galena (SPb)

It appears in the form of cubic grains of steel grey colour, metallic lustre.

Only 7 samples provided galena.

4.7 Ilmenite (TiO_2)

It appears in tabular form with a hexagonal outline, black colour, and submetallic lustre.

Of the 273 samples studied, 47 did not show ilmenite, with its content varying in the different concentrates. Thus, its highest concentration is located in the samples found in the area east of Saraguro and 28 de Mayo, which could be related to the Tres Lagunas granitic complex.

4.8 Pyrite (S_2Fe)

It appears in the form of irregular grains, sometimes pyritohedral and combined in different forms, metallic lustre, brass-yellow colour.

Of the 273 samples studied, 108 do not show pyrite. They are probably not minerals of great importance.

4.9 Fluorite (F_2Ca)

It appears in prismatic and more or less angular grains; it is commonly white and colourless, transparent. Under ultraviolet light, its coloration is violet.

Only 53 samples show fluorite; additionally, some samples may be accompanied by ilmenite and/or rutile, as occurs with those from the El Carmelo-La Bonita sector.

4.10 Siderite (CO_3Fe)

In only seven samples were grains of this ferrous carbonate found, presenting a black to brownish-coffee colour. Its content was very low.

4.11 Rutile (TiO_2)

It appears in the form of prismatic crystals or in the form of elongated needles, red to reddish-brown in colour, vitreous; the highest concentration is in the non-magnetic fraction.

Of the 273 samples studied, 142 did not show rutile; sometimes ilmeno-rutile aggregates can be found.

In 12 samples, the presence of anatase was found, a mineral species that is a polymorph of rutile.



5. CONCLUSIONS

- The study of heavy minerals using dense liquids, and their identification through non-sophisticated techniques, constitutes a useful and not very costly tool.
- The semi-quantitative mineralometric study is a useful method in the prospecting of economic minerals, especially when working on a regional scale.
- The recognition and identification of minerals such as: scheelite, gold, wolframite, galena, cassiterite, etc., can allow us to locate interesting zones or areas that can be studied later in detail, maintaining this technique and executing a systematic sampling that allows us to evaluate these areas at 100%.

6. REFERENCES

PIERRE DEVISMES (1978) Photographical Atlas of Detrital Minerals.

PAUL F. KERR (1977) Optical Mineralogy.

EOIN H. MACDONALD (1983) Alluvial Mining: The Geology, Technology and Economics of Placers.

HENRY B. MILNER (1962) Sedimentary Petrography.

ARPS C.E.S. (1970) Zircon in granites, gneisses and metasediments from western Galicia (N.W. Spain). Boletín geológico minero.

PARFENOFF A., POMEROL C., TOURENQ J. (1970) Les minéraux en grains, méthodes d'étude et détermination.

Ing. Ramiro Bermúdez A.
CORDILLERA REAL PROJECT

Attachments: Data tables, location maps, and list and type of study.

SEMI-QUANTITATIVE POLYMINERAL STUDY OF HEAVY SEDIMENTS OF THE CORDILLERA REAL

Ing. Ramiro Bermúdez / INEMIN / British Mission — March 1989-April1990

Symbology

★ Microtraces ≠ Traces △ Scarce □ Occasional and number of grains ● Common ○ Abundant + Dominant ① Mineral identified by ultraviolet lamp

Sample N° CR	Mass (grs)	% Magnetics	% Heavies	Scheelite ①	Zircon ①	Gold	Wolframite	Cassiterite	Hematite	Ilmenite	Rutile	Kyanite	Columbite- Tantalite	Siderite	Pyrite	Fluorite- Apatite ①	Garnet	Tourmaline	Biotite	Mica	Muscovite	Topaz	Chromite	Observations
RB-001	44.2	21.0	51.0							□					□	□			□					
RB-002	16.6	15.0	64.5	□1	□					□					△		○			□				
RB-003	26.5	2.6	59.2												●		●			□				
RB-004	33.0	3.9	75.0														○					△		
RB-005	41.9	6.4	67.0							△							+	□		●				
RB-006	57.2	1.5	48.0		□				□						△		●			●				
RB-007	71.6	5.7	67.7	★	≠				□?				□		●		●			○				
RB-008	22.05	13.5	54.6										□		△		△		○					chalcopyrite □
RB-009	35.7	1.1	61.6	□1	★				□						△		○		○		○			
RB-010	75.6	1.1	44.1		★								□				○	□		□				
RB-011	79.9	-	25.4		□3										●		△			○				
RB-012	34.7	0.5	28.2	□2	★									□	○		△			○				
RB-013	24.5	25.3	51.8		□					△					●	△	△			○				
RB-014	22.2	3.1	16.6							□						□	△	□						
RB-015	19.2	2.6	56.7		★										△		△		●	○				
RB-016	39.5	2.1	76.7		□1		□1	□1		□		□		□	△		○	□	△	○				
RB-017	48.4	0.2	28.0													△?			△	●				
RB-020	68.2	1.3	33.8									△		△	△			□		●				
RB-022	135.4	5.0	29.5		★								□3						●		△			
RB-023	71.7	4.8	37.9		□3					□			□		△	△			●					chalcopyrite □
RB-024	112.9	4.0	49.6		□3					△					△			△	△	△				
RB-026	9.1	-	30.7																●	○				
RB-027	20.5	3.4	58.0							△			□		●			□	△					
RB-028	11.2	-	17.8							△							□			●				
RB-029	11.0	-	23.6		★					△			□		●		●	□	△	●				
RB-030	149.4	32.7	14.7		★								△		△				△		●			
RB-031	29.05	20.9	34.5	□7									□		○				●	●				
RB-032	17.0	4.7	27.6		★								△		●		○	□		●				
RB-034	36.6	37.1	11.7	□3	★	□4	□3?	□1					△		●				●				□3	Au laminar
RB-035	59.0	5.7	28.0	□3	★	□1				△				□	●		●		●	○			□	small grains Au
RB-049	15.2	13.8	84.2	□2	★					△					●		●		●				□?	
RB-050	12.7	34.6	59.8	□2	★	□1				△					●		●			△			□?	small grains Au

Sample N° CR	Mass (grs)	% Magnetics	% Heavies	Scheelite ①	Zircon ①	Gold	Wolframite	Cassiterite	Hematite	Ilmenite	Rutile	Kyanite	Columbite- Tantalite	Siderite	Pyrite	Fluorite- Apatite ①	Garnet	Tourmaline	Biotite	Mica	Muscovite	Topaz	Chromite	Observations
RB-052	8.7	4.5	94.2		★					□				□	△		+							
RB-053	32.6	0.6	72.3		★						□						+		●		●			
RB-054	32.5	58.7	23.0		★					△			△				●	△	○					
RB-055	15.1	53.0	26.4	□1	★	□2?				△			△		△		●		○		○			chalcopyrite □
RB-056	87.3	39.9	56.0		★					△?			△		●	△?	●	△	□				□?	
RB-057	26.7	39.0	25.8	□2	★					●	□				△	□5			○		△			
RB-058	39.7	36.0	32.9		★					△	□				△		●		○		△			
RB-059	7.0	47.0	24.2	□2	★					△	□				●	□3	○		○		△			
RB-060	67.8	65.0	15.9	□3	★					△				□		□2	+		●		○			
RB-062	12.9	34.0	60.4	□4	★								□		△	□2	●		○		○			
RB-068	3.5	4.2	71.4		★					△			△				○	△			●			
RB-069	27.89	30.4	67.0				□4			□?					●		○							blende △
RB-070	10.4	0.9	40.3												●						●			
RB-071	8.1	1.2	85.1		★										△	★	+	□?			○			
RB-072	58.4	40.2	58.5													△				○				
RB-073	2.8	10.7	57.1		□1					△			□				△		△		△			
RB-074	31.5	24.4	71.7		★								□?		●		△							blende △
RB-075	23.9	14.0	79.0	□5	★					△							□	□	○		○			
RB-076	16.5	18.7	69.6	□2	★					□						□?	□	□			○			galena □
RB-077	18.9	25.0	62.1	□2	□								△			□?	△				○			galena □
RB-078	20.4	13.0	70.5		□						□				○	□?	○	□			△			
RB-092	26.3	17.8	71.1		□					△			△?		△		●		●		●		□	staurolite □
RB-093	65.5	11.0	78.3	★	★	□3	□?			●					●		+	△?			●		△	staurolite □/ blende □
RB-094	35.5	47.0	40.5	★	★	□1				△					△		+		△		△			blende △/anatase □2
RB-095	36.8	8.4	63.3	□3	★	□1	□			●					+	□?	+	△	●		●			blende □/galena △?
RB-096	60.3	56.5	41.9	★	★	□10				●					●		○	□						blende □/galena △
RB-097	16.8	10	68.0	□4	★	□?				△					△		○			○	●		△?	
RB-098	58.4	52.7	43.8	★	★	□6	□?			△	△?				●		○	△					△	blende △
RB-099	25.5	42.7	50.9	★	★								△		●		○						△	blende △/galena △/hematite △
RB-100	30.2	14.5	72.5	★	★										○		○	△					△	blende △/galena △/hematite △
RB-101	26.7	6.7	64.0				□2			□					○		○							
RB-102	23.9	33.0	54.3	★	★	□7				△	△				○	□?	○	△						hematite △/ Au laminar and small grains
RB-103	10.8	47.0	50.9	□5	★					△	△			□	○		○		○				△	
R. Collay	7.8	2.5	69.2		★	□1	□?			△			□		+		○	△		△				hematite □/anatase □
A-126	13.0	26.0	63.8	□21	★	□1	□			△	□				+		○		△				□	hematite □
A-127	10.8	25	66.6		★	□1				△					○		△							hematite □/galena □/staurolite □
A-128	10.3	36.9	45.6		★	□2				△	□		△		●		△	□						blende □/hematite □
A-129	7.2	4.2	52.7		★						□							□		○				hematite △
A-130	17.5	43.4	50.2	□?	★	□1							△?		●	□								

★ Microtraces ★ Traces △ Scarce □ Occasional and number of grains ● Common ○ Abundant + Dominant ① Mineral identified by ultraviolet lamp

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★ Microtraces ≠ Traces △ Scarce □ Occasional and number of grains ● Common ○ Abundant + Dominant ① Mineral identified by ultraviolet lamp

Sample N° CR	Mass (grs)	% Magnetics	% Heavies	Scheelite ①	Zircon ①	Gold	Wolframite	Cassiterite	Hematite	Ilmenite	Rutile	Kyanite	Columbite- Tantalite	Siderite	Pyrite	Fluorite- Apatite ①	Garnet	Tourmaline	Biotite	Mica	Muscovite	Topaz	Chromite	Observations
A-131	8.0	20.0	66.6	★	★					□?	△						△						□	hematite ●
A-132	4.5	24.4	60.0		★					□								□?	△					hematite ●
A-133	12.9	40.3	48.0		★						□				○			△	●					hematite ○
A-134	36.8	15.7	74.7												□				□					hematite ○
A-135	19.4	7.7	92.2		□3					△								□		□				
A-136	13.1	0.2	98.4		★										□								△?	hematite △
A-137	8.6	0.5	97.6		□4								△					△						●
A-138	7.0	0.5	68.0		□						□		□											hematite □
A-139	14.9	5.37	83.8		□2						□				●			□		○				hematite ○
A-140	12.0	1.6	89.0		□5										○		△	△?			○			
A-141	25.6	0.1	44.5		□5										△			□			○			anatase □2/hematite ○
A-155	12.5	27.0	56.3		★	□1		□									○	△	□			□		
A-156	41.4	1.7	23.1		★	□2		□		●							○	△		△				anatase □/hematite △
A-157	25.6	0.8	30.0			□3				△			□?				○		□					
A-158	17.6	0.1	26.7	□8	≠	□2					△								□					
A-159	13.4	0.3	13.4		≠	□1					□						△		○					anatase □1/hematite □
A-160	24.4	0.2	39.7	□	≠													△	△		△			staurolite ○
A-161	24.3	2.0	64.1	★	≠		△				□3						○	□						
A-162	13.6	0.07	16.9	□1							□						○	□	△					anatase □2
A-163	19.2	70.3	18.7		≠		△?				□							□						anatase □2
A-202	12.2	50.0	45.9		≠					△					△		△					△	□	
A-204	1.6	3.0	81.2		≠	□2	△			□	□2				△				△			△		blende □
A-205	3.0	73.0	26.6		★					□					△					○				
A-206	9.2	2.0	71.7	□6											○									blende △
A-207	8.7	-	17.2												△			△?		●				hematite □
A-208B	10.8	-	16.6	□6			●								△					○				hematite △
A-209	7.5	2.7	68.0		≠										●					○				
A-209C	14.9	-	51.6		★		△?										△	△		△				
A-210	11.8	6.8	55.0							△	□2				□2	△		□	△	□				
A-211	23.1	5.2	77.9		★					△	□?				△				△		△			hematite △
A-214	20.2	0.5	57.4		□						□1									●				hematite ○
A-215	6.4	51.6	39.0								□				○		△			●			□	hematite ○
A-216	21.0	74.8	20.4				△?								△		○			△				hematite □1
A-217	11.0	-	57.2		□												○			○				
A-218	9.5	-	22.5														□			○				hematite △
A-219	9.8	-	35.7														○			○				
A-220	21.5	-	23.7												△	□?				●				
A-221	11.3	-	41.5			□1					□									●				chalcopyrite □
A-222	12.3	39.8	55.2	□2	≠										△					●				
A-222 (3-4)	37.5	-	2.1														□			●				

Sample N° CR	Mass (grs)	% Magnetics	% Heavies	Scheelite ①	Zircon ①	Gold	Wolframite	Cassiterite	Hematite	Ilmenite	Rutile	Kyanite	Columbite- Tantalite	Siderite	Pyrite	Fluorite- Apatite ①	Garnet	Tourmaline	Biotite	Mica	Muscovite	Topaz	Chromite	Observations
A-223	54.4	2.9	92.8	□2											○	□3	△	□		△				
A-224	13.9	2.0	97.1		★					△							△	□?						
A-224	8.8	34.0	69.3		★										○					○				
A-225	39.1	38.0	92.3		★					●					●		□	□		●				
A-226	11.4	-	17.5								□				△					○				
A-226V	4.8	-	54.3		★					△								□		○				
A-227 (1-4)	83.6	-	3.1		★													□		●				
A-227V	71.3	78.9	13.1		★					△					△	□?	△	□	○		△			
A-228	37.6	13.2	41.2	★	★							□			△	□?	●							
A-229	17.3	2.9	68.2														●							
A-229V	17.2	9.3	83.1	□3	★										△	△?	●		○			△		
A-230	17.8	80.9	17.9	□	≠	○				△	△					△?	△					□		blende □/micro Au
A-230V	8.7	27.6	47.1		★					△	△													
A-231	9.7	-	24.7		□					□							□			●		□		
A-231V	57.9	86.5	13.6		≠					△					△			△?			△			
A-232	24.2	57.4	32.2		★	□1				□					△									blende △
A-232V	19.6	-	47.4		★										●		△	□		●				
A-233V	15.6	7.0	20.5		≠	□4		□?			□													
A-234V	52.4	58.0	41.7		★						□													
A-235V	21.2	38.0	56.6		★			□?								□?				●				
A-236	33.2	62.0	38.5		≠	□2									○								□?	
A-236V	11.0	-	81.8		★															●				
A-237V	83.2	47.0	52.4		≠					□														
A-238V	29.3	42.0	52.5		≠	□2		□3		△														hematite □
A-239V	34.5	64.0	33.9			□5				○													○?	
A-240V	67.8	55.0	43.2		≠	□2				○								□					□?	
A-241V	48.2	81.0	8.5		≠						□?													
A-242	33.9	-	95.5		★		□?				△						○	△		●				
A-243	39.1	22.0	75.7		★		△?			●											△			
A-244	43.4	1.6	91.9		★		△?								△		○	△		●				
A-245	9.3	53.7	45.1	□11	≠	□16				●	□				○									
A-246 (1)	38.7	2.8	70.2		≠			□?			□				△		●	□?						
A-246 (2)	27.6	2.5	78.9		★			□?		△					△		○	□						galena
A-247	42.8	32.0	66.8		★	□6				○	△				●		●							
A-248	28.9	-	93.7		★			□?									○	△		○				
A-249	26.7	-	73.4	□3	≠												●	△	△					
A-250 (1)	28.3	91.0	4.5	□2	≠						□				△		□			●				
A-250 (2)	63.3	91.6	3.4		≠			□?		△					△		△	□		●				
A-251	26.9	55.7	10.4	□3	≠					△					○		□							
A-252	34.0	43.0	30.5	★	≠					□						△	△	□?	△		□			
A-253	36.1	12.0	29.9	★	≠					□	□?				○		△							□

★ Microtraces

≠ Traces

△ Scarce

□ Occasional and number of grains

● Common

○ Abundant

+ Dominant

① Mineral identified by ultraviolet lamp

Fourth Annual Report (1989-1990)

★ Microtraces ≠ Traces △ Scarce □ Occasional and number of grains ● Common ○ Abundant + Dominant ⓘ Mineral identified by ultraviolet lamp

Sample N° CR	Mass (grs)	% Magnetics	% Heavies	Scheelite ⓘ	Zircon ⓘ	Gold	Wolframite	Cassiterite	Hematite	Ilmenite	Rutile	Kyanite	Columbite- Tantalite	Siderite	Pyrite	Fluorite- Apatite ⓘ	Garnet	Tourmaline	Biotite	Mica	Muscovite	Topaz	Chromite	Observations
FV-142	109.2	80.8	17.6		□10	□1				△					○									
FV-143	47.3	68.7	17.1	□4	★		□?			△							○			●				
FV-144	21.4	11.0	14.0	□3	★		□?										△			○				
FV-145	52.7	5.3	3.9		*		□?								△		□		●					
FV-146	25	29.6	5.6	□2	★												□		○					
FV-147	38.1	15.0	23.3		★										□	□	△		○		□			
FV-148	32.8	44.0	5.4		*											★	△		●		□			
FV-149	54.2	4.0	32.2	★	*											□	△		●		△			
FV-150	73.0	73.5	10.6		*		□?																	hematite □
FV-151	68.6	72.0	64.4					□?		□							△	□					△?	hematite △
FV-152	57.0	74.0	15.6		★			□?		□									△					hematite □
FV-153	106.8	84.0	12.8		★					□						□		□						hematite □
FV-154	46.7	81.6	9.2		★					△										●				hematite △
PO-83	22.2	28.3	-		★					□	□									●				
PO-84	6.1	29.5	-		□					●					△									
PO-85	11.4	-	-		□					●														hematite □
PO-86	5.2	30.7	-		□															□			△?	
PO-87	1.6	-	-							□						★								
PO-88	1.7	52.9	-	□4	□20	□2				△	□				△									
PO-89	0.4	-	-								△					□1	□							
PO-90	35.7	-	-													≠?								
PO-91	69.0	11.8	-		★					○	□							□						
P-104	33.9	17.9	-		□2						□					*								
P-105	40.2	33.0	-												□			□		□				
P-106	31.3	22.3	-	□2	★										△			□		□				
P-107	39.1	15.8	-	□5	★	□2					△				●		△		□			□		
P-109	35.9	40.9	-		□					□					●									
P-110	26.0	88.4	-		□						□				□									
P-112	24.4	25.8	-		★										□					△		□?		
P-114	25.3	35.1	-		□	□1		□?			△				●	*	△			●				
P-115	22.1	25.7	-	□1	□										●					△				
P-116	45.9	-	-												○	+								
P-117	20.2	48.0	-		□						△						△							
P-118	25.3	47.8	-	□10	□		□?			□					●		△			□				
P-119	23.4	41.4	-		□										○									
P-120	14.3	39.8	-		*						□				●		△			△				
P-121	4.6	80.4	-		□					□							△		△					
P-122	2.5	44.0	-												△		△	□						
P-123	1.8	88.8	-		□											□1								
P-124	1.6	37.5	-		□											□	△			△				
P-169	7.9	-	-		*												△			△				anatase □

Sample N° CR	Mass (grs)	% Magnetics	% Heavies	Scheelite ①	Zircon ①	Gold	Wolframite	Cassiterite	Hematite	Ilmenite	Rutile	Kyanite	Columbite- Tantalite	Siderite	Pyrite	Fluorite- Apatite ①	Garnet	Tourmaline	Biotite	Mica	Muscovite	Topaz	Chromite	Observations
A-164	87.5	50.7	-		□					○						△	△		□					
A-165	47.3	9.0	-		*					○													□?	
A-166	45.6	25.2	-		★					○									□					
A-167	11.7	18.8	-		*					○								△						
A-170	65.6	36.7	-	□1	★					○							△	□						anatase □
A-171	16.1	62.1	-	□2	★		□?									★					△			
A-172	7.1	42.2	-	□10	★					△														
A-254	10.4	14.4	-	★	*					△					□					○				
A-255	28.2	8.5	-	□4	□					○	□													
A-256	15.5	7.7	-		*		△?				□										△			hematite □
A-257	10.5	-	-		★		△?				□?										△			
A-262	42.3	28.6	-	□1	★		△?			○														
P-113	10.8	23.1	-												●					○				
MC-125	33.4	13.7	-	□18	□										○	★			△				△?	
MC-127	20.9	52.6	-		□	□1					□						○							
MC-128	23.5	70.6	-	□2	□	□1					□						○					△		
MC-129	46.9	4.9	-		□						□				△		○				●			
MC-130	17.5	2.2	-		□										△		●				●			
MC-131	6.7	17.9	-	□4	★		□?				□				△		●			●				
MC-132	30.1	22.2	-		□					□					△		△			●				
MC-133	26.5	33.2	-		*		□?				□				△		△							
MC-134	47.5	46.9	-	□2	*						★				△					●				blende △
MC-135	3.6	41.6	-		★						□						△							
MC-136	122	87	-	□2	★	□4									□		●							
AP-180	67.1	97.7	-	★	*						□				△				□				□?	
A-268	7.0	-	-	□5	*								□?				△		□					anatase □
A-188	9.3	22.5	-	□15	□	□8					□				●				△					coarse and fine grain Au
A-182	2.9	75.8	-	□11	□						□3										△			
AP-187	6.2	-	-		★			□2?			△						△				△			
AP-185	2.8	25.0	-	□1	★											□2					●			
AP-173	2.6	15.3	-		□						△					□2								
AP-178	4.6	-	-		★	□1	□?										△			●			□	
AP-183	27.0	97.0	-	□20	★					□	□					□1								
A-186	6.0	1.6	-	□1	★						○						●							
AP-190	3.8	34.2	-	□6	★	□6					□												△?	
A-276	19.6	47.4	-	□6	★												○						△?	
A-267	9.0	13.3	-	□5	*					□	□									●				anatase □
A-263	27.6	79.7	-		*	□6									○				□					galena □
AP-179	3.6	44.4	-	□25	★																△			
AP-175	6.9	7.2	-	□5	□																○			
A-265	8.4	13.0	-	□5	*					○	□2				□		○							anatase □4

★ Microtraces

✱ Traces

△ Scarce

□ Occasional and number of grains

● Common

○ Abundant

+ Dominant

① Mineral identified by ultraviolet lamp

Fourth Annual Report (1989-1990)

★ Microtraces ✱ Traces △ Scarce □ Occasional and number of grains ● Common ○ Abundant + Dominant ⓘ Mineral identified by ultraviolet lamp																								
Sample N° CR	Mass (grs)	% Magnetics	% Heavies	Scheelite ⓘ	Zircon ⓘ	Gold	Wolframite	Cassiterite	Hematite	Ilmenite	Rutile	Kyanite	Columbite- Tantalite	Siderite	Pyrite	Fluorite- Apatite ⓘ	Garnet	Tourmaline	Biotite	Mica	Muscovite	Topaz	Chromite	Observations
A-266	3.5	11.4	-		✱												△		△					
AP-189	10.5	20.9	-	□2	★										+		○							
AP-181	17.6	99.4	-	□3	□	□3				△	□1				□	□4			□					
A-272	4.6	13.0	-		□										□					△				
A-270	2.9	-	-		✱		□?			□	△								△					
AP-184	7.7	79.2	-												□		○			△				
AP-176	2.0	20.0	-								□				□					△				
AP-177	4.1	7.3	-								□						□							
AP-174	5.6	5.3	-								□									○			□?	
A-269	3.9	-	-		✱	□3	□?			△														anatase □1
A-275	5.8	20.6	-		✱		□?				□								○					anatase □3
A-279(1)	62.7	82.1	-		★					△	△				△		□							
A-279(2)	48.5	80.2	-		□					○	○												□?	
A-273	44.6	49.3	-	□7	★										+									hematite △
A-278	52.0	17.6	-	□5	✱	□4				○							△							
A-271	15.8	48.1	-		★		□?								+	□2							□?	
A-264	6.5	-	-		□								□?		□					△				
A-274	34.1	81.5	-		□		△?								△									
A-280	30.9	69.5	-		✱		□									□1							△?	
A-277	54.2	90	-		□	□1									△									
RB-193	15.5	12.9	-												△					○				
RB-194	81.0	1.6	-												△					○				
RB-195	62.3	1.1	-								□2				△					○				
ML-147	10.5	77.1	-	□20	★					△	□				●									
ML-146	9.9	73.7	-	□1	✱					△	□				△									
ML-145	27.5	76.7	-	□20	✱	□3				△	□						△							
ML-144	11.5	36.5	-	□3	★						□				□	□?	△							
ML-148	27.4	90.8	-	□5	★						□												□?	
ML-137	3.0	40.6	-	□30	★					□	□				●		□							
ML-141	16.3	80.9	-				□?			□	□				□					△			□?	
ML-142	11.2	69.6	-	□20	★		□?								△		△						□?	
ML-143	23.1	66.6	-	□60	★	□1		□?		□	□				△		△							
ML-150	22.8	46.4	-	□5	★	□1				□														
ML-149	10.9	57.7	-		★		□?				□?								△				□?	
ML-138	13.9	25.8	-	□10	★	□1				□	□				△		△							
ML-139	34.1	64.5	-	□20	✱	□11				□							△							
ML-140	42.4	71.4	-	□8	✱	□1				△	□						□		□				□?	
ML-136	4.3	34.8	-	□1											○		□							

APPENDIX 7b

Qualitative chemical analysis by XRF of heavy mineral sediments
from the Cordillera Real of Ecuador

English translation by Stalyn Paucar (2026)



ESCUELA POLITÉCNICA NACIONAL

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TELEX 22650 ESPONA
Quito-Ecuador

FACULTAD DE GEOLOGÍA MINAS Y PETRÓLEOS

R E P O R T

Analysis: Chemical (qualitative) by XRF
Requested by: British Mission and INEMIN
Samples: Heavy sediments (Cordillera Real of Ecuador)
Number: 29 (twenty-nine)
Costo: None. Inter-institutional Collaboration
Department: Geology
Laboratory: X-Ray
Analyst: Tlga. Med. María de los Ángeles Arauz

Equipment used

- Spectrometer: Philips PW 1410
- Detector: Flow and scintillation
- Crystal: LiF200
- Tube: Tungsten

Fourth Annual Report (1989-1990)

No.	Code	Ba	Ce	Zr	Sr	Rb	Pb	As	Zn	Ni	Cu	Fe	Co	Mn	Cr	Ti	V	Ag	Au	Y	Nb	Mo	Sn	Sb
1	CR-P-086	d		f	d		d		m	d	d	f		f	f	f				trz	trz			
2	CR-P-087	d		d	m	d			d	trz	trz	f		m	m	m	trz	trz						
3	CR-P-090	d		d	d	trz			d	trz	d	f		m	d	m	trz							
4	CR-P-107	d	trz	m	m	trz			d	trz	trz	f		f	d	f				trz				
5	CR-P-114	d	d	f	m	trz	trz		d	d	trz	f	trz	m	d	f				trz				
6	CR-P-119	d	d	f	m	trz	m	m	d	trz	d	f	trz	m	trz	f								
7	CR-P-122	trz		d	d	trz		trz	d		trz	f		f	trz	f								
8	CR-P-123			m	d				d	d	trz	f		f	d	f								
9	CR-A-164		d	f	d		trz		d		trz	f		d	trz	f				trz	trz			
10	CR-A-163		m	f	trz	m	d		d		trz	f		m		f		trz	trz	d	trz	trz	trz	
11	CR-A-170		trz	f					d		trz	f		m	trz	f								
12	CR-A-171	d	d	f	d	trz	d	d	d		trz	f		f		f					trz			
13	CR-MC-131	d	trz	f	m				trz		trz	f		m		f								
14	CR-MC-136	trz	d	f	m		trz		d	trz	trz	f		f	d	f				d			d	
15	CR-MC-134	trz	d	f	d		trz	trz	d		trz	f		f	trz	f		trz	trz	d	trz	trz		
16	CR-A-129	trz	trz	d	d	d			d		trz	f		f	d	m				d				
17	CR-MC-125	m		d	d			trz	d	trz	d	f		d	d	f	trz							
18	CR-AP-180		d	f	trz	trz	m	m	d		trz	f	d	f	trz	f		trz	trz		d	d	trz	
19	CR-A-186		d	f	d		d		trz		trz	f	trz	f		f			trz	m				
20	CR-AP-187		trz	f	d		trz	trz	d		trz	f		f	trz	f								
21	CR-A-215	trz	d	f	d	d	trz		d	trz	trz	f	trz	f	trz	f								
22	CR-AP-178	trz	trz	f	d	d	d	d	d	trz	trz	f		f	trz	f		trz		trz				
23	CR-AP-173	d		d	d	trz	trz	trz	m	d	m	f		m	d	m								
24	CR-AP-183	trz	d	f	trz		d	d	d		d	f		f	trz	f								
25	CR-A-256	d	d	f	trz	d	trz		d		trz	f		m		f				trz	trz			
26	CR-A-262	trz	trz	f	d	trz	trz		d		trz	f		m	trz	f								
27	CR-MC-133	d	d	f	m	d			d	trz	trz	f		d	trz	m		trz					trz	
28	CR-P-118	d	d	f	m	d	d	d	d	d	d	f		m	trz	m				trz				
29	CR-A-255	d	d	f	d	d			d		trz	f		m	trz	f						trz		

strong (f), moderate (m), weak (d), traces (trz).

Quito, April 12, 1990
Ing. Tomás Espinosa
DECANO



ESCUELA POLITÉCNICA NACIONAL

APARTADO 2759
TELEX 22650 ESPONA
Quito-Ecuador

FACULTAD DE GEOLOGÍA MINAS Y PETRÓLEOS

R E P O R T

Analysis:	Chemical (qualitative) by XRF
Requested by:	British Mission and INEMIN
Samples:	Heavy sediments (Cordillera Real of Ecuador)
Number:	46 (forty-six)
Costo:	None. Inter-institutional Collaboration
Department:	Geology
Laboratory:	X-Ray
Analyst:	Tlga. Med. María de los Ángeles Arauz

Equipment used

– Spectrometer:	Philips PW 1410
– Detector:	Flow and scintillation
– Crystal:	LiF200
– Tube:	Tungsten

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No.	Code	Ba	Ce	Zr	Sr	Rb	Br	Pb	As	Zn	Ni	Cu	Fe	Co	Mn	Cr	Ti	Ag	Au	Y	Nb	Mo	Sn	Sb
1	CR-RB-060	m	m	f	f	d	m	trz	trz	d	d	trz	f		f	d	f			d				
2	CR-MP-93	m	d	m	d	m	f	trz	d	d	d	d	f	trz	f	d	f	trz		d				
3	CR-MP-94	m	m	m	d	d	m		trz	d	d	trz	f		f	d	f			trz				
4	CR-MP-95	m		d	d	d	f		trz	d	trz	d	f		f	trz	f			d				
5	CR-MP-100	d		f	m	d	f	d	d	d	trz	d	f	d	f	trz	m			trz				
6	CR-MP-103	m	d	m	d	d	d		m	m	d	d	f	trz	f	d	f			trz				
7	CR-A-126	d	trz	f	trz	d	d	d	d	trz		d	f		f	trz	f			d			trz	trz
8	CR-A-127	f	d	f	d	d	d	trz	m	d		d	f		f	d	f	trz		trz	trz		trz	trz
9	CR-A-130	m	trz	m	m	trz	m	d	d	d	trz	d	f	trz	m	d	f							
10	CR-A-135	d	trz	m	m	trz	m	d	d	d	d	d	f		m	d	f			trz				
11	CR-A-136	trz		d	m		m			trz		trz	f		m	m	f							
12	CR-A-138	m	trz	f	f	d	f	trz	trz	d	trz	trz	f		m	d	f			trz	trz			
13	CR-A-141	d	d	f	d	d	m		trz	m	trz	d	f		m	d	f			d	trz			
14	CR-A-155	trz	trz	m	d	trz				trz	trz	trz	f		f	d	f			d				
15	CR-A-156	d	m	f	m	d	trz	trz	d	d		trz	f		f	trz	f		trz	m				
16	CR-A-159	d	d	f	d	d	d	trz	f	d	d	d	f	trz	f	d	f	trz	trz	d	d			
17	CR-A-161	d	m	f	d	f	d	d	d	d		d	f	trz	f	d	f		trz	m				
18	CR-A-163	trz	d	f	m	d	m	d	d	d		d	f	d	f	trz	f			d	trz			
19	CR-A-204	trz		f	d	trz	m	m	m	f	d	d	f		f	trz	f	trz		trz				
20	CR-A-209C	trz		m	f	d	m	trz	d	d	d	trz	f		m	d	f			d				
21	CR-A-215	trz	trz	d	m	d	f		trz	d		d	f	d	m	d	f			d	trz			
22	CR-A-216	d	d	f	m	d	m		d	trz		d	f	d		trz	f			d	trz			
23	CR-A-247		f	f	trz	f	d	trz		d		trz	f	trz	f	d	f	trz	trz	f	d	trz		

strong (f), moderate (m), weak (d), traces (trz).

No.	Code	Ba	Ce	Zr	Sr	Rb	Br	Pb	As	Zn	Ni	Cu	Fe	Co	Mn	Cr	Ti	Ag	Au	Y	Nb	Mo	Sn	Sb
24	CR-A-228	d	m	f	m	m	m	d	d	d	trz	trz	f		f	trz	f			m	trz			
25	CR-A-230V	d	d	f	d	d	d	trz	trz	m	d	trz	f		m	d	f			trz	trz			
26	CR-A-239V	d	trz	d	d		m			d		d	f		m	d	f	trz	d					
27	CR-A-240V	d	trz	f	d	trz	d		trz	d		d	f		m	f	d		Au					
28	CR-A-246(P1)	trz	m	m		m	m	trz	trz	m	d	trz	f		f	d	f			d	trz			
29	CR-A-246(P2)	m	m	m	trz	d	d			d	d	trz	f		f	d	f		trz	m	trz			
30	CR-A-248	trz	m	m		m	d			m	d	trz	f		f	d	f		d	m	trz			
31	CR-A-233V			f	d		d	trz	d	trz		d	f	trz	d	d	f		trz		trz			
32	CR-A-235V	d	trz	f	d	trz	d	trz		d	trz	d	f		m	d	f							
33	CR-A-238V	d	trz	f	d	d	m			d	trz	d	f		f	d	f							
34	CR-A-242	trz	f	f		d	m			d		trz	f	trz	f	d	f			m	trz	trz		
35	CR-A-243	trz	d	f	d	d	m			d		trz	f		f	trz	f		trz	d	trz			
36	CR-A-244	trz	d	m	trz	d	m			m	trz	trz	f		f	d	f	trz		m				
37	CR-A-249		trz	f	m	m	f			trz		trz	f		f	d	m							
38	CR-A-250(P2)	d	f	f	d	d	m	d		d	trz	d	f	trz	f	d	f		trz	f	trz	trz		
39	CR-FV-143	m	m	f	d	d	d	d	d	m	d	d	f		f	d	f		trz	d	trz	trz	trz	
40	CR-FV-144	trz	f	f	d	m	d		d	m	trz	d	f	trz	f	trz	f	trz		f	trz	d		
41	CR-FV-145	m	f	f	m	d	trz	trz		d		trz	f	trz	f	d	f			f	d	d		
42	CR-FV-146	trz	f	f	m	f	d	d		d		trz	f	d	f	trz	m			f	m	d		
43	CR-FV-150	d	trz	f	f	d	m	trz	d	d		d	f		f	trz	f							
44	CR-FV-151	m		d	d		d				trz	d	f		m	d	f							
45	CR-FV-152	d	trz	f	f	d	d	trz		d		d	f		m	trz	m							
46	CR-FV-154	d	d	f	m	d	d	trz	trz	d		d	f		m	trz	f				trz			

strong (f), moderate (m), weak (d), traces (trz).

Quito, April 3, 1990
 Ing. Tomás Espinosa
 DECANO



ESCUELA POLITÉCNICA NACIONAL

APARTADO 2759
TELEX 22650 ESPONA
Quito-Ecuador

FACULTAD DE GEOLOGÍA MINAS Y PETRÓLEOS

REPORT

Analysis:	Chemical (qualitative) by XRF
Requested by:	British Mission and INEMIN
Samples:	Heavy sediments (Cordillera Real of Ecuador)
Number:	31 (thirty-one)
Costo:	None. Inter-institutional Collaboration
Department:	Geology
Laboratory:	X-Ray
Analyst:	Tlga. Med. María de los Ángeles Arauz

Equipment used

– Spectrometer:	Philips PW 1410
– Detector:	Flow and scintillation
– Crystal:	LiF200
– Tube:	Tungsten

Observations: In the last column of the results table, there is an entry corresponding to minerals present with magnetic properties; in the case of the analyzed samples, this should correspond to Magnetite and/or Titanomagnetite.

This treatment is necessary prior to analysis via XRF.

No.	Code	Ba	Ce	Zr	Sr	Rb	Pb	As	Zn	Ni	Cu	Fe	Co	Mn	Cr	Ti	Ag	Au	Y	Nb	Mo	Sn	Sb	Mgt
1	A-136		trz	f	d				trz	trz	trz	f		f	trz	f			d	d				
2	A-190	d	d	f	m	d	trz		d	d	d	f		f	d	f		trz	m	trz				
3	A-276		f	f	trz	m	d	d	d		trz	f	trz	f		f		trz	m	d	d			
4	A-267		m	f	m	d	d	d	trz		trz	f	d	f		f			f	trz		trz	trz	
5	AP-179	d	d	f	d	d	m	m	d	trz	d	f		f	trz	f	trz	trz	m	trz				
6	A-265	trz	d	f	d	f	d		trz		trz	f	trz	f		f			f					
7	A-189	trz		f	d	d		trz	trz		trz	f	trz	f		f								
8	AP-181	trz	d	f	d			trz	d		trz	f		f	trz	f		d	trz					
9	A-270	trz	d	f	trz	m	d		trz	trz	trz	f		d		f								
10	A-269		d	f	trz	m	d		trz	trz	trz	f	trz	m	trz	f			f	d				
11	A-275	d	d	f	trz	d	d	d	d		d	f		m	d	f		trz?		trz		d		
12	A-279(2)	f	trz	f	m	d	m		trz		m	f	trz	f	trz	f	trz			trz				10%
13	A-273	d		f	d	trz	d	m	d	trz	d	f	trz	m	d	f								10%
14	A-271	d	d	f	d	d	m	m	d	trz	d	f	d	d	d	f								
15	AP-174	m		trz	m	d			d	d	d	f		m	d	d				trz				
16	A-264			f	trz	trz		trz	trz		trz	m		d	trz	m						trz		
17	A-274	d	d	f	m	d	m	m	d	d	d	f	d	m	m	d								15%
18	A-280	d	trz	f	d	d	trz		d		d	f		f	trz	f								5%
19	RB-195	d	trz	d	m	d		trz	d	trz	d	f		d	d	m	trz							
20	ML-146		d	f	m	trz	d		d	trz	d	f	d	f	d	f				d				
21	ML-145	trz	d	f	d	d	d		d		d	f		f	trz	f		trz	d	d				
22	ML-144	d	m	f	d	d	trz	trz	d	trz	trz	f		m	trz	f		trz	d	trz	trz			
23	ML-141	d	d	f	m	d	m		m		trz	f		f	m	f	d		trz					
24	ML-142	m	m	f	m	m	d	d	m	d	d	f		f	m	f		trz	trz	trz	trz			
25	ML-143	m	m	f	m	d	d	d	d		trz	f		m	trz	f	trz		trz					
26	ML-149	d	d	f	d		d	d	d	trz	d	f	trz	m	d	f		trz	d	trz				
27	ML-138	d	m	f	m	d	d	m	m	d	d	f	trz	m	d	m								
28	ML-139	d	m	f	d	d	d	d	d	trz	trz	f		m	d	f				trz	trz			
29	ML-140		d	f	d	d	d	d	d		trz	f		f	d	f				trz	trz			
30	ML-136	d	d	f	m	d	d	trz	trz	trz	d	f	d	m	trz	f								
31	ML-148	d	d	f	m	d	d		d		d	f		f	d	f				trz	trz			

strong (f), moderate (m), weak (d), traces (trz), Magnetite (Mgt)

Quito, May 7, 1990
 Ing. Tomás Espinosa
 DECANO

List and type of study of the heavy sediments

Sample No.	Location	Type of study
RB-001	R. Patate	PS
RB-002	R. Patate	PS
RB-003	R. San Pablo	PS
RB-004	R. Ulba	PS
RB-005	R. Pastaza	PS
RB-006	R. Blanco	PS
RB-007	R. Verde	PS
RB-008	R. Pastaza	PS
RB-009	R. Pastaza	PS
RB-010	R. Machay	PS
RB-011	R. Pastaza	PS
RB-012	R. Topo	PS
RB-013	R. Zuñag	PS
RB-014	R. Alao	PS
RB-015	R. Maguazo	PS
RB-016	R. Alao	PS
RB-017	R. Alao	PS
RB-020	R. Atillo	PS
RB-022	Q. Pancún	PS
RB-023	R. Tingo	PS
RB-024	R. Cebadas	PS
RB-026	R. Upano	PS
RB-027	R. Upano	PS
RB-028	R. Upano	PS
RB-029	Zuñac	PS
RB-030	Salado Chico	PS
RB-031	Salado Grande	PS
RB-032	R. Cugusha	PS
RB-034	R. Colimbo	PS
RB-035	R. Abanico	PS
RB-049	Monte Olivo	PS
RB-050	R. Pimampiro	PS
RB-052	R. Verde	PS
RB-053	R. Verde	PS
RB-054	Sta. Bárbara	PS
RB-055	La Bonita	PS
RB-056	R. Sibundoy	PS
RB-057	Sta. Bárbara	PS
RB-058	Q. Agua Amarilla	PS
RB-059	Sta. Bárbara	PS
RB-060	Q. de las Piedras	PS/XRF
RB-062	Q. El Oso	PS
RB-068	Q. Los Incas	PS
RB-069	R. Muyo	PS
RB-070	R. Muyo	PS
RB-071	R. Verde Grande (stream)	PS
RB-072	R. Antisana	PS
RB-073	Q. Soledad	PS
RB-074	Q. Soledad	PS
RB-075	Base 4	PS
RB-076	Cosanga headwaters	PS
RB-077	Cosanga headwaters	PS
RB-078	Cosanga headwaters	PS
MP-092	R. Oyacachi	PS
MP-093	R. Oyacachi	PS/XRF
MP-094	R. Cariyacu	PS/XRF
MP-095	R. Chalpi	PS/XRF
MP-096	R. Oyacachi	PS
MP-097	R. Cedro	PS
MP-098	R. Oyacachi	PS
MP-099	R. Stan María	PS
MP-100	R. San Juan Grande	PS/XRF
MP-101	R. San Juan Chico	PS
MP-102	R. Quijos	PS
MP-103	R. Quijos	PS/XRF
R. Collay	R. Collay	PS
PO-083	Taday	PS
PO-084	R. Dudas	PS
PO-085	R. Dudas	PS
PO-086	R. Dudas	PS/XRF
PO-087	R. Paute (tributary)	PS/XRF
PO-088	R. Juval	PS
PO-089	R. Collay (tributary)	PS
PO-090	R. Paute (tributary)	PS/XRF
PO-091	R. Pindilig	PS
P-104		PS
P-105	Cosanga headwaters	PS
P-106	Cosanga headwaters	PS

Cordillera Real Geological Research Project

Sample No.	Location	Type of study
P-107	Cosanga headwaters	PS/XRF
P-109	R. Aliso	PS
P-110	R. Azuela	PS
P-112	R. Salado	PS
P-113	R. Salado (tributary)	PS
P-114	R. Salado (tributary)	PS/XRF
P-115	R. Cascabel	PS
P-116	R. Salado	PS
P-117	R. Diviso	PS
P-118	R. Diviso	PS/XRF
P-119	R. Diviso	PS/XRF
P-120	R. Diviso	PS
P-121	R. Saraurco	PS
P-122	Saraurco N.	PS/XRF
P-123	R. Hualaringo	PS/XRF
P-124	R. Hualaringo	PS
ML-136	Q. Garrapatal	PS/XRF
ML-137	R. Sudio (tributary)	PS
ML-138	Q. La Chisparosa	PS/XRF
ML-139	R. Laurel	PS/XRF
ML-140	R. Condué	PS/XRF
ML-141	R. Cofanes	PS/XRF
ML-142	Q. Pílares	PS/XRF
ML-143	R. San Jorge	PS/XRF
ML-144	R. Laurel	PS/XRF
ML-145	R. Palmar	PS/XRF
ML-146	Q. La Industria	PS/XRF
ML-147	Q. Las Juntas	PS
ML-148	Q. El Bícudo	PS/XRF
ML-149	Q. Bijagual	PS/XRF
ML-150	R. La Chispa	PS
A-126	R. Moriré	PS/XRF
A-127	S. M. Cuyes	PS/XRF
A-128		
A-129	Amazonas	PS
A-130	R. Cuyes (tributary)	PS/XRF
A-131	R. Cuyes	PS
A-132	R. Cuyes	PS
A-133	R. Cuyes	PS
A-134	R. Cuyes	PS
A-135	R. Cuyes	PS/XRF
A-136	R. Cuyes	PS/XRF
A-137	R. Cuyes	PS
A-138	R. Cuyes	PS/XRF
A-139	R. Collay (tributary)	PS
A-140	R. Chorro Blanco	PS
A-141	Q. Honda	PS/XRF
A-155	R. Betas	PS/XRF
A-156	R. Macuchi	PS/XRF
A-157	R. Zavala	PS
A-158	R. Zavala (tributary)	PS
A-159	R. Zavala (tributary)	PS/XRF
A-160	R. Zavala (tributary)	PS
A-161	R. Zavala (tributary)	PS/XRF
A-162	R. Sta. Cleotilde	PS
A-163	R. Piuntza	PS/XRF
A-202	R. Molor	PS
A-204	R. Sangurima	PS/XRF
A-205	Chigüinda	PS
A-206	Q. Montanero	PS
A-207	Q. Chorro Blanco	PS
A-208B	R. Collay	PS
A-209	C. Negro	PS
A-209C	C. Negro	PS/XRF
A-210	R. Negro	PS
A-211	R. Negro	PS
A-214	R. Negro	PS
A-215	R. Negro	PS/XRF
A-216	R. Negro	PS/XRF
A-217	R. Negro	PS
A-218	R. Negro	PS
A-219	R. Negro	PS
A-220	R. Negro	PS
A-221	R. Negro	PS
A-222	R. Shiro	PS
A-222 (3-4)	R. Shiro	PS
A-223	R. Shiro	PS

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Sample No.	Location	Type of study
A-224	Q. Esmeraldas	PS
A-224	Q. Esmeraldas	PS
A-225	R. Martirio	PS
A-226	R. Collay	PS
A-226V	R. Yacura?	PS
A-227 (1-4)	R. Arenillas	PS
A-227V	R. Blanco?	PS
A-228	R. Jíbaro	PS/XRF
A-229	R. Arenillas	PS
A-229V	R. Jíbaro	PS
A-230	R. Pilares	PS/XRF
A-230V	V. hermoso	PS
A-231	R. Pilares	PS
A-231V	La Canela	PS
A-232	R. Pilares	PS
A-232V	R. Panguri	PS
A-233V	R. Pilares	PS/XRF
A-234V	R. Panguri	PS
A-235V	R. Collay	PS/XRF
A-236	R. Gualaceo (tributary)	PS
A-236V	R. Panguri	PS
A-237V	R. Panguri	PS
A-238V	La Canela	PS/XRF
A-239V	R. Panguri	PS/XRF
A-240V	R. Panguri	PS/XRF
A-241V	Q. Palmales	PS
A-242	Q. Flor Amarilla	PS/XRF
A-243	Q. San Francisco (tributary)	PS/XRF
A-244	R. Numbala	PS/XRF
A-245	R. Numbala	PS
A-246(1)	Q. El Oso	PS/XRF
A-246(2)	Q. El Oso	PS/XRF
A-247	R. Numbala	PS/XRF
A-248	R. Numbala (tributary)	PS/XRF
A-249	R. Cuyes	PS/XRF
A-250(1)	Q. Yerbabuena	PS
A-250(2)	Q. Yerbabuena	PS/XRF
A-251	R. Cuyes	PS
A-252	R. Cuyes	PS
A-253	R. Cuyes	PS
FV-142	R. Isimanchi	PS
FV-143	R. Isimanchi	PS/XRF
FV-144	R. Isimanchi	PS/XRF
FV-145	R. Isimanchi	PS/XRF
FV-146	R. Isimanchi	PS/XRF
FV-147	R. Isimanchi	PS
FV-148	R. Isimanchi	PS
FV-149	R. Isimanchi	PS
FV-150	Q. La Colmena	PS/XRF
FV-151	Q. La Colmena	PS/XRF
FV-152	Q. La Colmena	PS
FV-153	Q. La Colmena	PS
FV-154	R. Vergel	PS/XRF
A-169	R. Negro	PS
A-165	R. Negro	PS/XRF
A-166	R. Negro	PS
A-167	R. de la Plata	PS
A-170	R. Negro	PS/XRF
A-171	R. Ingenio	PS/XRF
A-172	R. Plateado	PS
A-254	R. Tambo Blanco	PS
A-255	R. La Merced	PS/XRF
A-256	R. Verde	PS/XRF
A-257	R. Verde (tributary)	PS/XRF
A-262	R. Quimi	PS/XRF
MC-125	R. Blanco (Patate)	PS/XRF
MC-127	Q. Juan Ibarra	
MC-128	Q. Mueses	
MC-129	Monte Olivo	PS/XRF
MC-130	R. San Miguel (tributary)	PS
MC-131	R. San Miguel	PS/XRF
MC-132	R. San Jorge	PS
MC-133	R. San Jorge	PS/XRF
MC-134	R. Condué	PS/XRF

Sample No.	Location	Type of study
MC-135	R. San Jorge	PS
MC-136		PS/XRF
AP-180	R. Salado Chico	PS/XRF
A-268	R. Tutupali	PS/XRF
A-188	R. Collanes	PS
A-182	R. Consuelo	PS
AP-187	R. Palora	PS/XRF
AP-185	R. Palora	PS/XRF
AP-173	R. Galgalán	PS/XRF
AP-178	R. Playas	PS/XRF
AP-183	R. Colimbo	PS/XRF
A-186	R. Palora	PS/XRF
AP-190	R. Venado	PS/XRF
A-276	Q. Piuntza	PS/XRF
A-267	R. Yacuchicangari	PS/XRF
A-263	R. Cambana	PS
AP-179	R. Salado Grande	PS/XRF
AP-175	R. Ashillán	PS
A-265	R. Tutupali	PS/XRF
A-266	R. Tutupali	PS
AP-189	R. Encantado	PS/XRF
AP-181	R. Alshi	PS
A-272	R. Espadillas	PS
A-270	R. Ortega	PS/XRF
AP-184	R. Alao	PS
AP-176	R. Upano	PS
AP-177	R. Purshi	PS
AP-174	Q. Quishal	PS/XRF
A-269	R. Ortega	PS/XRF
A-275	Q. El Guando Chico	PS/XRF
A-279(1)	R. Chicaña	PS
A-279(2)	R. Chicaña	PS/XRF
A-273	R. Campana Urcu	PS/XRF
A-278	R. Cantzama	PS
A-271	R. Campana Urcu	PS/XRF
A-264	R. Tutupali	PS/XRF
A-274	Q. El Guando Grande	PS/XRF
A-280	R. Chicaña	PS/XRF
A-277	R. Salado	PS
RB-193	R. Cunguentza	PS
RB-194	R. Ojal	PS
RB-195	R. Tutanangoza	PS/XRF

XRF = X-ray fluorescence

PS = semi-quantitative mineral

RB/fac. 90.04

